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HARD X-RAY IMAGING FACILITY
FOR SPACE SHUTTLE

A Scientific and Conceptual Engineering Study

by the

Hard X-Ray Imaging Facility Definition Team

November 1976

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Report for

National Aeronautics and Space Administration
Goddard Space Flight Center

through

University of California, San Diego
Department of Physics
La Jolla, California 92093

Contract No. NAS 5-22375

Report prepared by:

L. E. Peterson, University of California, San Diego
H. S. Hudson, University of California, San Diego
G. Hurford, California Institute of Technology
D. Schneible, Ball Brothers Research Corporation



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Preface

This report describes the conceptual definition of an instrument to obtain images of solar and cosmic X-ray sources. The work was accomplished by a Facility Definition Team (FDT) operated through the University of California, San Diego (UCSD). This scientific team was constituted in response to NASA's Announcement of Opportunity-5 (AO-5), dated 15 July, 1974 requesting proposals for participation in planning advanced instruments for solar research to be flown on the Space Shuttle in the 1980's.

The Hard X-Ray Imaging Facility Definition Team was funded under contract NAS-5-22375 to UCSD from the Goddard Space Flight Center, starting in April 1975 and presently continuing. Task subcontracts were let to the California Institute of Technology for a Scientific Tradeoff Study and to the Ball Brothers Research Corporation for a Conceptual Engineering Study. The instrument, in early stages of development, was proposed for the Space Shuttle Orbit Flight Tests (OFT) and for the Spacelab-2.

This report consists of several sections describing the work of the Team. Section 1 summarizes this work and briefly describes the instrument as presently conceived. Section 2, updated from an Interim Report published in May 1975 describes the Scientific Objectives. The Scientific Tradeoff Study, Section 3, was performed by Dr. Gordon Hurford at CalTech. The Conceptual Engineering Study, Section 4, was accomplished at BBRC under the close supervision of the Team. Finally, management plans developed by the Team are described in Section 5. These include operation either as a National Facility or under the direction of a PI-led consortium.

Although many individuals have contributed to this work, the Team is particularly indebted to Dr. Adrienne Timothy of NASA's Solar Physics Program Office, Dr. Werner Neupert, GSFC Solar Physics Study Scientist, and C. G. Stouffer, GSFC Study Technical Director and Contract Liaison.

Laurence E. Peterson
Team Leader
November 1976

OUTLINE OF REPORT

PREFACE

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- II. SCIENTIFIC OBJECTIVES
- III. CONCEPTUAL STUDIES FOR SCIENTIFIC TRADEOFFS
- IV. ENGINEERING STUDY
- V. MANAGEMENT CONCEPTS

SECTION I

SUMMARY REPORT

SCIENTIFIC AND ENGINEERING STUDY

FOR A

HARD X-RAY IMAGING INSTRUMENT

I. SUMMARY REPORT

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SCIENTIFIC AND ENGINEERING STUDY
HARD X-RAY IMAGING INSTRUMENT

I. SUMMARY REPORT

A. Facility Definition Team:

Four Facility Definition Teams were organized by NASA in 1975 in response to proposals solicited by AO#5 (15 July 1974) to study advanced instrumentation for solar observations from the Space Shuttle. The requirement for these observations during the Shuttle era was established by the 1973 Woods Hole Summer Study under the auspices of the National Academy of Sciences (1). This report gives a summary of the work of the Definition Team for a Hard X-Ray Imaging System. The present membership of the group (October 1976) which has expanded slightly since initial selection, is shown in Table I-1. Also listed in the Table are consultants appointed by NASA, and by the Team Leader, to assist the group in their efforts.

The Team was generally charged to define a "Hard X-Ray Imaging Facility" for Spacelab Astronomy Missions. Specifically this included:

1. Detailed scientific justification and representative observing programs for facilities,
2. Definition of Hard X-Ray Imaging System facilities and support systems, performance requirements for attaining facility scientific objectives,
3. Preliminary design concepts and engineering requirements,
4. Definition of representative analyzers or detectors for recording the imaged or collimated hard X-ray radiation,
5. Concepts for facility operations and user involvement,
6. Description of areas requiring additional research or development,
7. Periodic reviews of related Spacelab engineering design and support system studies, and
8. Other tasks to be specified by the Study Scientist.

The work of the Team to meet these objectives was accomplished through a regular series of meetings, with appropriate assignments and tasks between the meetings. Initially the Team re-examined the scientific merits for astronomical hard X-ray imaging, and the basic requirements for a system which would provide significant new capabilities. Although the study was directed primarily toward solar work, it was recognized that the requirements for cosmic X-ray imaging are nearly identical. An Interim Report, which described these efforts, was prepared in May 1975 and appeared in the GSFC Astronomy Shuttle Project Report, June 1975 (2). By this time the basic instrumental goals and interfacing characteristics had been established. Section II provides an updated detailed scientific discussion, based on the properties of the instrument as finally derived.

The Team was fortunate in having as one of its members Dr. H. F. van Beek of the Space Research Laboratories, Utrecht, Netherlands, who is project scientist on the Hard X-Ray Imaging System (HXIS) successfully proposed for the Solar Maximum Mission (SMM) to be launched in 1979. This instrument is described in the Utrecht proposal (3) and the Study Phase Report (4).

It was early recognized that many techniques are possible for hard X-ray imaging. Although most of these are based on variants of the wire grid collimator, the relative merits of the various possibilities in terms of sensitivity, image reconstruction and completeness, detector requirements, feasibility of implementation, etc., were unclear. Accordingly, a "Scientific Tradeoff Study" was accomplished by Dr. Gordon Hurford of CalTech (5). Here the many concepts were examined and their merits compared on a common basis, so that a configuration for an engineering evaluation could be established. This work was completed about December 1975. The complete study appears in Section III of this report.

Although various members of the Team or their laboratory staff had expertise in technical aspects of grid imaging systems, it was deemed necessary that an engineering study of the instrument concept be undertaken by an independent organization. Accordingly, Ball Brothers Research Corporation (BBRC), Boulder, CO, was selected to investigate the engineering requirements, the feasibility of a conceptual design, and identify problem areas for further study. Accommodation information was based on that supplied in (6) and it was assumed a pointer in the "Small Instrument Pointing System" (SIPS) (7) class would be available. The BBRC work was initiated in March, 1976 and completed in July, 1976. The Final Report (8) contained herein as Section IV, was released in September, 1976.

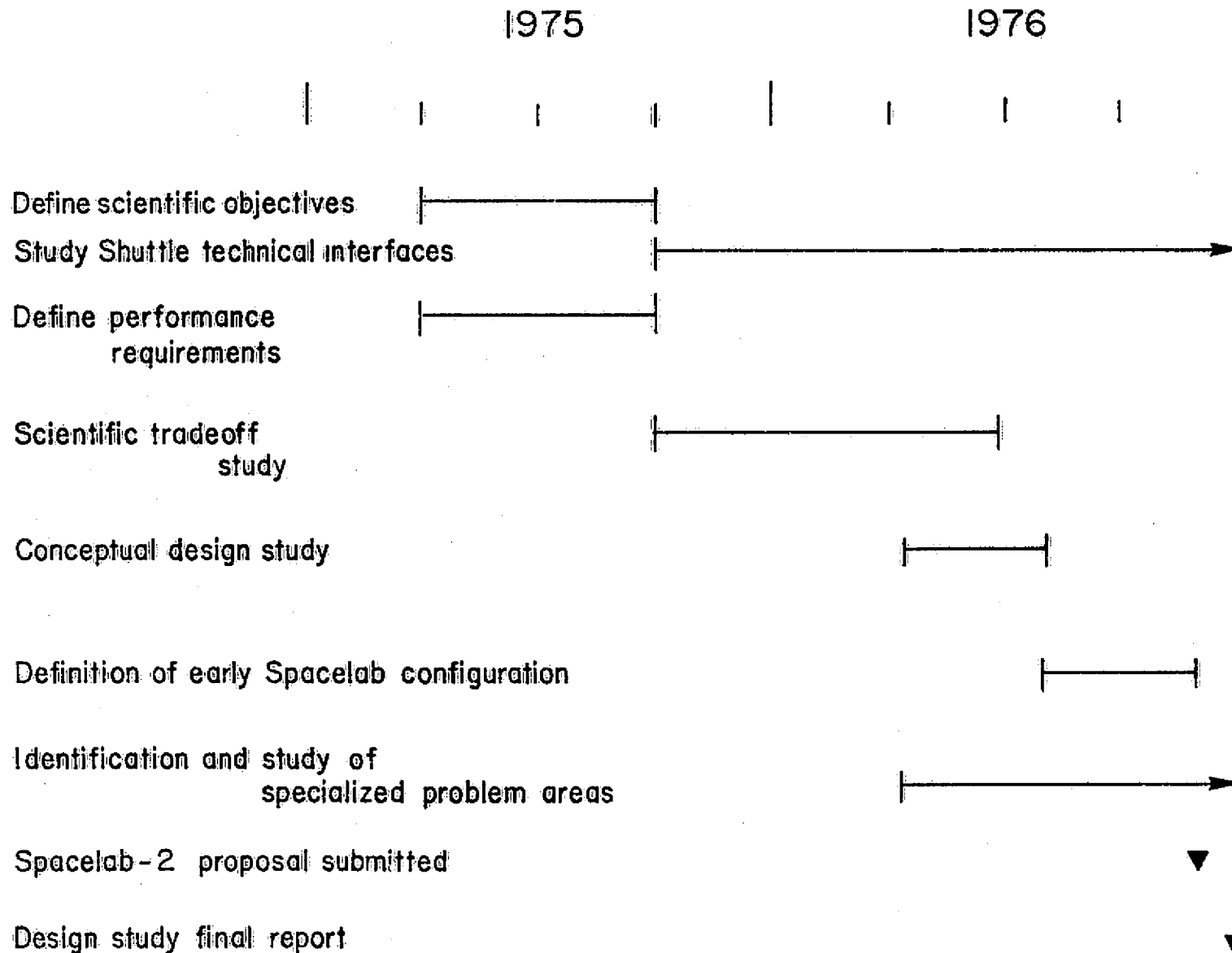
The operation and management of the instrument being defined was also considered by the Team. A management concept based on a facility supplied and operated by NASA, directed by the users, was described in a report issued in December 1975 (9). Since this instrument was proposed in response to the AO for OFT (10) and SL-2(11), a scheme based on a consortium led by a Principal Investigator was also developed. Both these plans are included in Section V of this report.

The deliberations and accomplishments of the Team are in the detailed minutes of each meeting (12). Table 1-2 indicates each meeting, its location, and principal activities. Figure I-1 shows the schedule under which the work of the Team was performed.

As of this report date, the Team has defined and demonstrated the feasibility of a Shuttle-accommodated instrument for imaging hard X-rays. This device will have capabilities considerably beyond anything previously flown. This instrument, in an evolutionary form, has been proposed for inclusion on the early Shuttle Program on either OFT-6 or Spacelab-2. Various studies required to finalize a detailed engineering design study are now defined or underway. Section I-B of this Report essentially describes this early Spacelab configuration, while Section IV describes a slightly more advanced configuration. The differences are most notable in the counter design.

Hard X-ray Imaging Facility Definition Team

Phase A Study Schedule



Issued 3/78

TABLE I-1

Hard X-Ray Imaging Facility Definition Team

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TABLE I-1 (Continued)

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TABLE I-2

Facility Definition Team Meeting Summary

<u>Meeting Number</u>	<u>Location</u>	<u>Date</u>	<u>Summary of Objectives and Results</u>
1	UCSD*	3/21-22/75	Determine scientific objectives and necessary instrument characteristics. Discuss instrument techniques.
2	CIT*	5/5-6/75	Report written for Parker Committee, discuss preliminary instrumental tradeoffs, four recommendations.
3	GSFC*	6/26-27/75	GSFC presentations on Shuttle specs and engineering problems.
4	UCSD	8/21/75	Discuss instrument tradeoff study objectives with Hurford present.
5	UCB*	9/29-30/75	Instrument tradeoff interim report, management plan. Selected 3 designs for further study: responsive MECA, rot. mod. collimator, fan beam mod collimator.
6	BBRC*	12/15-16/75	BBRC presentations on Shuttle, SIPS. Final instrument scheme selected. Discussed management options.
7	BBRC	3/3-4/76	Specific instrument design to implement scheme for specs into Engineering Configuration Study. Response to AO's planned.
8	BBRC	5/19-20/76	Review progress on Engineering Study. Produced baseline instrument design parameters and study of special areas.
9	BBRC	6/30-7/1/76	Engineering Study Midterm Review. Identified special areas for further study.
10	BBRC	10/28-29/76	Final review of BBRC Study. Determined posture for response to OFT and SL-2 AO in terms of configurations, responsibilities, and management. Evaluated cost items.

*BBRC - Ball Brothers Research Company
 CIT - California Institute of Technology
 GSFC - Goddard Space Flight Center
 UCB - University of California at Berkeley
 UCSD - University of California at San Diego

REFERENCES

- (1) "Scientific Uses of the Space Shuttle," National Academy of Sciences 1974.
- (2) "Interim Reports of the Solar Physics Spacelab Facility Definition Teams," Goddard Space Flight Center 1975.
- (3) "A Hard X-ray Imaging Spectrometer for SMM," Space Research Laboratory (Utrecht) Proposal to NASA, 1974.
- (4) "A Brief Summary of the Solar Maximum Mission," Goddard Space Flight Center X-682-77-54, 1977.
- (5) Big Bear Solar Observatory #0167, 1977 (Section III of this report).
- (6) "Astronomy Spacelab Payload Accommodation and Interface Handbook," Goddard Space Flight Center, 1975.
- (7) "Low Cost Small Instrument Pointing System," Ball Brothers Research Corporation, 1975.
- (8) "Hard X-ray Imaging Instrument Engineering Study," Ball Brothers Research Corporation, 1976 (Section IV of this report).
- (9) "Management Plan for Development and Operation: Solar Hard X-ray Facility," L. E. Peterson (UCSD, 1975).
- (10) "A Hard X-ray Imaging Instrument for OFT," UCSD proposal to NASA, 1976.
- (11) "A Hard X-ray Imaging Instrument for Spacelab-2," UCSD proposal to NASA, 1976.
- (12) Minutes of the Hard X-ray Imaging Facility Definition Team, Meeting 1-9, UCSD.

B. Instrument Description

1. Introduction

The scientific objective of the Hard X-ray Imaging Instrument involve the study of nonthermal particles and high-temperature plasmas in various solar and cosmic phenomena, specifically solar flares. We describe these in full detail in Section II, and offer a brief summary in the following list:

- (a) Location, size, and shape of energetic-particle acceleration regions
- (b) Energetic relationships between thermal plasma and nonthermal particles
- (c) Acceleration mechanisms of nonthermal particles
- (d) Propagation of energetic particles through source structure

In order to obtain these objectives by studying hard X-rays, the following solar observational requirements are appropriate for an early Shuttle instrument:

- (a) Image flare structure in soft and hard X-radiation to 4 arc sec resolution
- (b) Separate soft X-ray (3-20 keV) from hard X-ray (20-100 keV) spectral bands
- (c) Obtain simultaneous coverage of the whole sun
- (d) Observe coronal emissions with 1 arc min resolution
- (e) Obtain time resolution ~ 1 sec
- (f) Obtain a sensitivity of ~ 0.1 ph $(\text{cm}^2\text{sec keV})^{-1}$ at 20 keV (~ 10 events per day).

Similarly, the cosmic X-ray astronomical objective may be summarized as

- (a) Image cosmic sources to 4 arc sec resolution over the 3-100 keV;
- (b) Determine size and structure of extended sources: supernova remnants, radio galaxies, clusters of galaxies.
- (c) Measure spectra of compact sources. The sensitivity for cosmic point sources should permit observation (3σ) in one hour of a source with 20 keV flux $\sim 1.0 \times 10^{-4}$ ph $(\text{cm}^2\text{sec keV})^{-1}$.

The Facility Definition Team adopted interface requirements to match the Hard X-ray Imaging Instrument to accommodation capabilities of the Space Shuttle. These included a small pointing system thought likely to be available. This implied:

- (a) Size $\sim 1.2 \times 1.2 \times 3$ m
- (b) Weight ~ 500 kg
- (c) Thermal environment 20 ± 2 °C
- (d) Maximum pointing stability ~ 0.2 arc sec
- (e) Power ~ 300 w maximum
- (f) Telemetry ~ 500 kbps maximum

In the following we briefly describe a hard X-ray imaging instrument meeting these observational objectives and interface criteria. The instrument is essentially that proposed for our early Spacelab flight, and is a predecessor to the final configuration.

2. Imaging System Configuration

(a) Grid Collimator Technique

At the short wavelengths ($\lambda \lesssim 6\text{\AA}$) being considered here, grazing-incidence reflection techniques fail, so the image must be formed by a wire-grid collimator that forms geometrical shadows from the object on a detector array. The basic principles are shown in Figure I-1. Early application of this concept to X-ray astronomy resulted in the modulation collimator, described initially by Oda (1965) and extensively in Bradt *et al.* (1968).

As shown in Figure I-1, a grid telescope, with appropriately spaced intermediate grid planes, defines three characteristic angles: the angular resolution, the period over which the beam patterns repeat, and the envelope or field of view. Depending on whether one has a one-dimensional or a two-dimensional grid structure, the response is in the form of fan beams or pencil beams. The energy range is determined by diffraction at low energies, and by grid transparency at high energies.

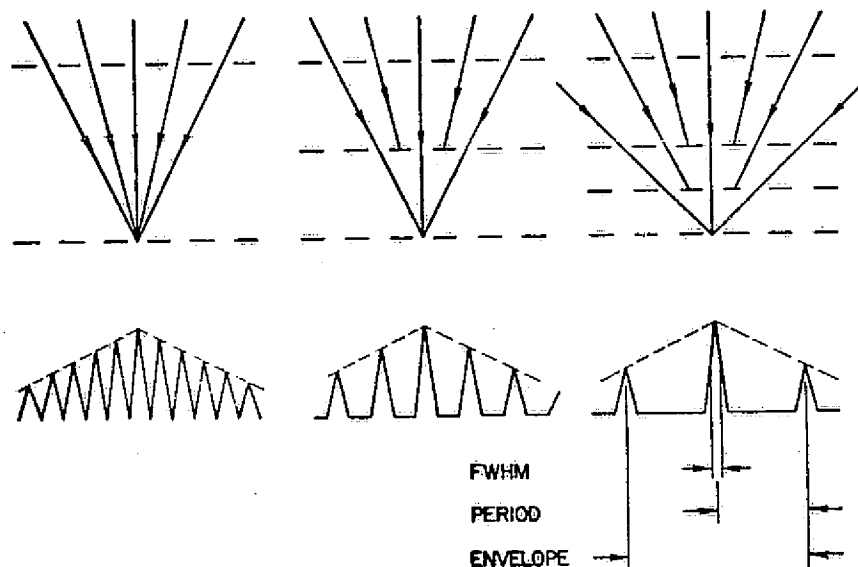


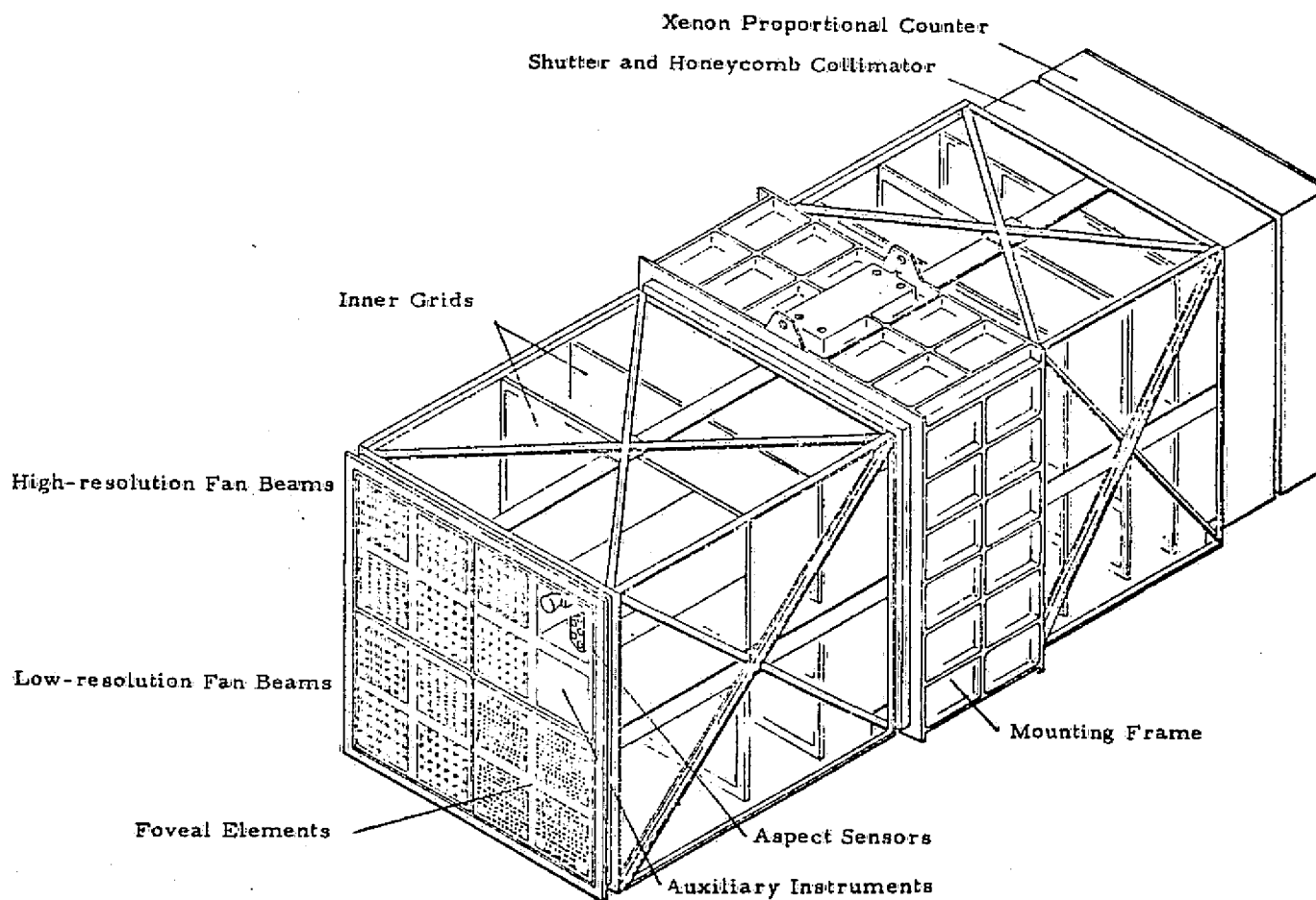
Fig. I-1. Explanation of grid-collimator telescope principles. The sequence from left to right schematically shows collimators with two, three, and four grids, and indicates the three characteristic angles of a collimator. In this example the periodic angle and the envelope angle are shown as equal, but this need not generally be the case.

The area of a grid plane may be divided into regions called subcollimators, each subcollimator having its own angular characteristics and detector element. In particular, different subcollimators may have responses at phased intervals to fill in a given angular range exactly; they thus simultaneously form a complete, unique image of an object whose size is less than the periodicity. This scheme resembles the imaging modulation collimator described in Bradt et al. (1968), and has the advantage over the usual modulation collimator that scanning across the source region is not required. In another application of the grid-collimator concept, the grid planes may be arranged so that the period is very large, resulting in a single pencil or fan beam, as in the standard single-field-of-view Soller or mechanical collimator. In the extreme application a two-dimensional pencil beam array may be formed by subcollimators, each properly phased to provide a direct two-dimensional image on an associated detector array. We call this a foveal array in our overall collimator layout.

(b) Configuration for Spacelab-2.

Many different combinations of characteristic angles, fan beams and pencil-beam arrays were studied to optimize the layout of the subcollimators for time resolution, sensitivity, image reconstruction, and engineering feasibility (Section III). This study also included scanning collimation schemes, such as the rotating modulation collimator, but these were rejected as insufficiently flexible.

As shown in Figure I-2, the actual layout is determined by structural, thermal, and detector considerations. The basic metering structure identified as a workable concept is a truss structure, divided into four quadrants, each of which supports grid planes and counter elements independently. Each grid plane is further divided into four collimator areas, called frames, for a total of 16 frames, each about 22 x 22 cm. These are further divided into 36 subcollimators which implies detector elements of about 3.8 cm x 3.8 cm. Table I-1 shows the distribution of subcollimators and their properties. The 16 collimator frames are distributed as follows: 6 high-resolution multiple fan beams; 4 low-resolution multiple fan beams; 4 two-dimensional foveal arrays; 2 reserved for auxiliary instruments. The angular scale of these grid systems will be shown superposed on the various astronomical objects in Section II.



I-2. Schematic layout of the Hard X-ray Imaging Instrument. Shown is a unitary metering structure/integrating structure that supports several grid planes. The telescope points to the left and the detectors and electronics are at the extreme right.

TABLE I -1
Subcollimator Layout

Elements	FWHM (arc sec)	Period (arc min)	Envelope (arc min)	Number of Grids	Effective Area per pixel (cm ²)
High-resolution Fan Beams (6x32)	4	2	41	6	3.8
Low-resolution Fan Beams (4x32)	64	34.1	41	6	5.0
Foveal (56 total)	4	-	-	10	3.4

Total number of subcollimators = 376
Effective area for distinguishing point sources = 26.2 cm²

The system described here is particularly well-suited for solar observations on from Spacelab, as described above. However, the modular construction, replaceable grid planes, and redundancies permit reconfiguring for a series of flights, or for specific objectives as the instrument and its operation evolve into the ultimate Facility envisioned by the Team.

(c) Detectors and Shutters.

Three possibilities exist for the large area multi-element detector array: position-sensitive proportional counters, an array of thin crystal NaI/CsI detectors of the "phoswich" variety (Peterson, 1975) or an array of cooled Li or Ge solid-state devices. Although each has its advantages in terms of efficiency, dynamic range, energy resolution, complexity, and engineering problems, cost considerations have dictated proportional counters with direct spatial read-out as an initial choice. Increased energy resolution and/or high-energy efficiency can be obtained with other types of counters in an upgraded configuration.

Obtaining large spectral and dynamic ranges requires careful considerations on counters, window thickness and area, and electronics. As shown in Figure I -2, the objectives can be met by a xenon proportional counter with moveable shutters to reduce the effective area for large events. Each quadrant has a physically distinct proportional counter, with four independent internal elements consisting of two cathode planes with orthogonal wire directions, read out in six groups each, to provide the spatial resolution. The anode plane is used for energy and pulse

shape discrimination. Figure I -3 shows the layout of each of the counters. The counter thickness is determined by the efficiency of xenon for the higher energy X-ray photons. The efficiency for xenon at a gas thickness of 40 atm - cm absorption is $\geq 80\%$ in the 2-35 keV range, and $\geq 50\%$ in the 70-80 keV range where the escape of 29 keV xenon K X-rays becomes significant.

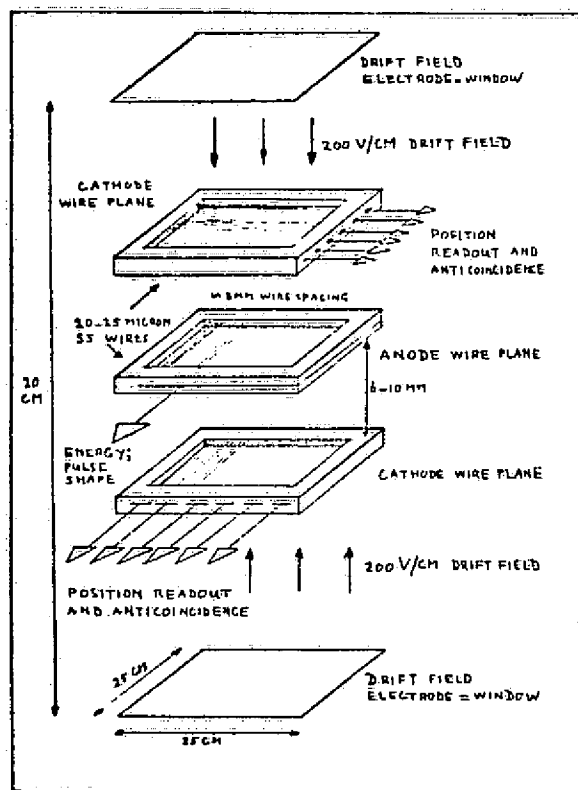


Fig. I -3. Layout of the position-sensitive xenon proportional counters. The depth of 20 cm consists mainly of drift volumes. The total HXII counter area contains 16 such units, with sub-groups of four each sharing a gas volume. Position sensitivity comes from discrete cathode-wire groupings.

A significant dynamic range problem for solar X-rays arises from the steepness of the flare spectrum which, between 1 and 100 keV, covers some 10 orders of magnitude in photon spectral flux. Good efficiency at the lowest energies is a requirement because of the need to observe cosmic X-ray sources, but the thin counter window therefore required creates an extremely high count rate during solar flares. This imposes the need for a variable geometry such as a moveable shutter system to be operated during flares. The shutter system proposed here covers all but 201 cm^2 of each subcollimator with 0.2 gm cm^{-2} of aluminum. This results in a two-peaked spectral distribution, as illustrated in Figure I -4. A simple mechanical activator will be controlled by software in the digital electronics.

Section IV of this Report describes a more advanced configuration with transmission argon counters for lower-background soft X-ray response.

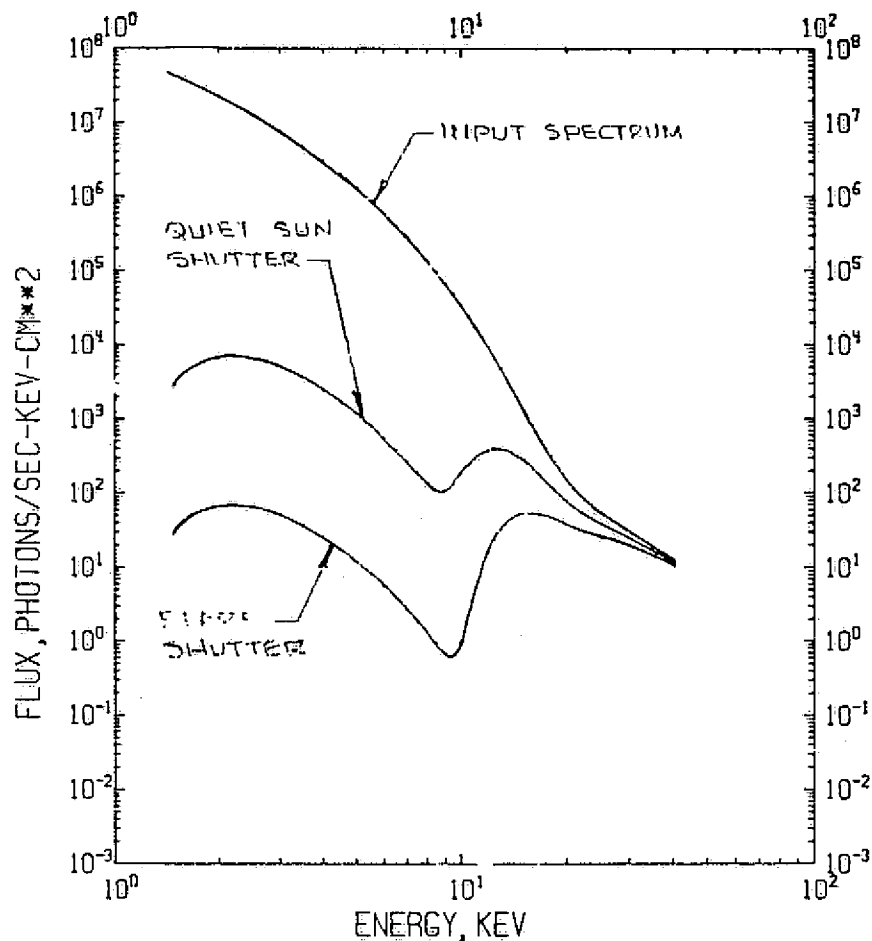


Fig. I-4. Model solar X-ray spectrum for a worst-case solar flare, illustrating the performance of two shutter assemblies in modifying the pulse-height spectrum. The shutter consists of 0.076 cm Al, and has holes of sizes suitable for quiet-sun and flare conditions. The model flare has thermal parameters $n_e^{2V} = 10^{50} \text{ cm}^{-3}$, $T = 2 \times 10^7 \text{ K}$; added to this is a nonthermal spectrum with spectral index 3 and 20 keV flux 100 photons $(\text{cm}^2 \text{ sec keV})^{-1}$. Such a large flare would have occurred roughly once a year during the OSO-7 observing period (Datlowe et al., 1974b), but flare occurrence is subject to large variations. If the shutter assembly permits observations of this flare, it can easily handle any flare likely to occur during a Skylab mission.

Figure I-4 shows a model solar input spectrum based upon plasma with an emission measure of 10^{50} cm^{-3} and an electron temperature of $2.0 \times 10^7 \text{ K}$. The nonthermal component is characterized by a power spectrum with a spectral index of 3 and a spectral flux of 100 photons $(\text{sec-keV-cm}^2)^{-1}$ at 20 keV. This peak flux for a hard X-ray event occurred roughly once every 300 days during the OSO-7 flight (Datlowe et al., 1974). Because one subcollimator has an effective area of about 3.8 cm^2 , the count rate per spatial element is $\sim 2 \times 10^3$ counts per second for this flare. Most counts will be located in a few subcollimators so that the maximum count rate will be of the order of 2×10^4 per second. All smaller flares, of course, may easily be measured if this extreme case does not saturate the system.

A spatial resolution of 0.5 mm gives unambiguous identification of the element in which the X-ray photon registers. The anode wire spacing of 1-2 mm leads to a maximum anode-to-cathode wire plane spacing of 5 to 10 mm. Therefore, the bulk of the counter thickness is a drift volume with the proportional region on the order of 1 to 2 cm thick. The proportional region is located in the center of the counter to reduce spatial uncertainties due to diffusion, and to permit a symmetric field configuration with lower voltages. At a fill pressure of 2 atm, each drift volume has a thickness $\sim 10 \text{ cm}$. Figure I-3 shows the counter layout.

The shutter mechanism may be located in between the grids or directly in front of the counter. Honeycomb collimators, whose field of view is on the order of 5° FWHM, reduce photon background due to production in the grids and support structure. The background is further reduced by wall-anticoincidence anodes, not shown in Figure I-3. Additional slat collimators will be placed between the grid planes as necessary to eliminate crosstalk between subcollimators. Each subcollimator area of a detector can provide anticoincidence rejection for other subcollimator areas.

3. Electronics

(a) Proportional Counter Front-End Electronics.

The anode-plane pulse is collected by a charge-integrating preamplifier as shown in Figure I-5. This is followed by a voltage amplifier and a shaping amplifier stage to create a pulse-shape suitable for pulse-height analysis. The output of the voltage amplifier is also routed to a pulse-shape analyzer (PSA) and pulse-shape discriminator (PSD). The pulse-height analyzer converts the height of the shaped pulse into a pulse width that is subsequently converted into a digital number by the Time-to-Digital Converter.

The two cathode planes are each divided into six groups of wires. Induced pulses on these wire groups are collected by charge-sensitive preamplifiers, followed by voltage and shaping amplifiers. Finally one

of the six low-level discriminators (LLD) in each direction will trigger to indicate X- and Y- position of the X-ray event.

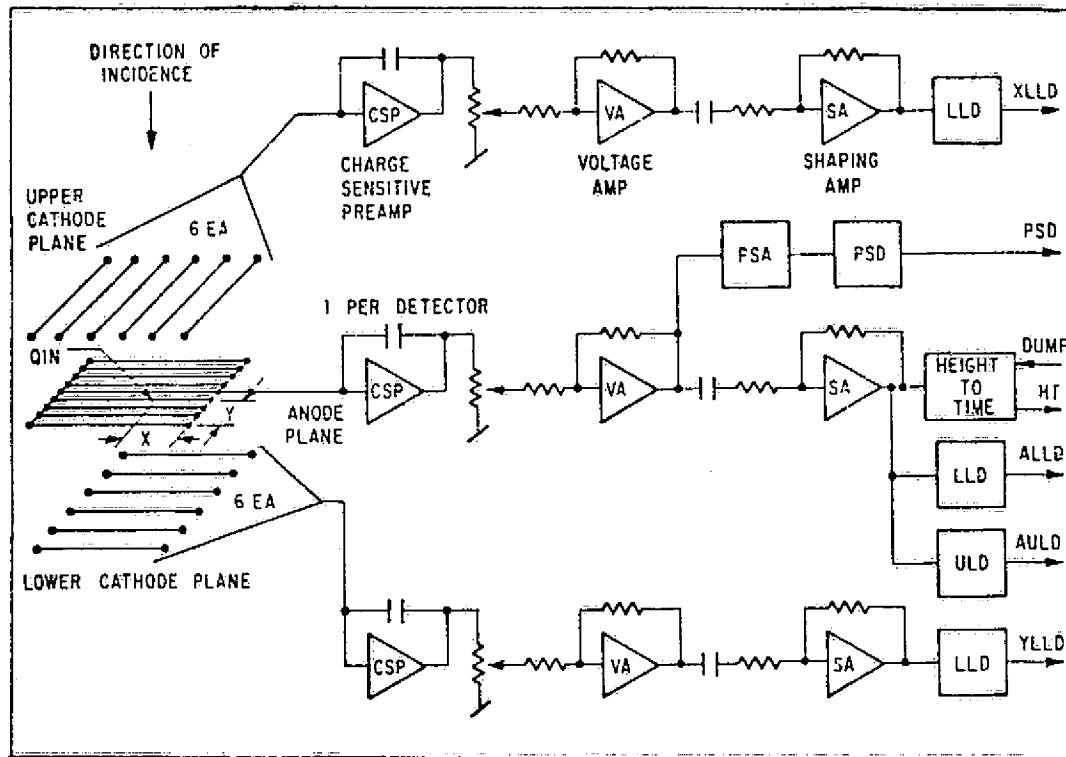


Fig. I-5. Analog electronics for the Hard X-ray Imaging Instrument.

The output of the shaping amplifier in the anode chain also goes to an LLD and a ULD, upper level discriminator, to determine whether the event is within the energy range of the detector. The output of the anode lower level discriminator (ALLD) is synchronized to a digital clock and normalized to a width defined by an integer number of clock periods in a front-end logic system. The normalized LLD (NLLD) time correlates other digital signals relevant to the detector's X-ray event. These signals are input to the first rank latch which is cleared when the NLLD output appears. Immediately following the clearing operation, inputs are sampled, and are stored in the latch. The time-to-digital converter converts the pulse-height into a number. The veto logic, which is programmable to accommodate various coincidence and anticoincidence schemes, determines whether the event is acceptable. The anticoincidence scheme includes cell-by-cell anticoincidence and additional anticoincidence from guard wires close to the proportional counter walls.

The X and Y positions are converted into a single position number identifying which spatial element gave rise to the event. If the event is acceptable, an event strobe is generated. The event time and position codes and first-rank discriminator data are then stored in a second rank latch to await the completion of the time-to-digital conversion of the pulse-height. When conversion is complete, second-rank data, PHA value and detector identification codes are loaded into buffer registers to await transfer to the event steering logic. The front-end logic may begin processing a new event when the microprocessor buffer register is loaded. In case of an invalid event, the pulse-height information is dumped and an event strobe is not generated.

(b) Microprocessors and Data Formatting.

The primary electronics interfaces are between the front-end electronics logic and the microprocessor system and between the microprocessor system and the Spacelab Command and Data Management Subsystem (CDMS). In addition to the front-end electronics there are other instrument functions which are controlled by and must therefore interface with the microprocessor system.

The basic internal electronics interface within the HXII is between the imaging detectors and the microprocessors which control their operation and prepare the data for transmission. As shown in Figure I-6, a total of four microprocessors will be used for interfacing with the 16 detectors. Two of the microprocessors will be used for event binning functions and a third will be utilized as a tagged-event processor. A 32-bit tag word is constructed as follows:

(1) Pixel Identification	-	5 bits
(2) Frame Identification	-	5 bits
(3) Pulse-Height Analysis	-	7 bits
(4) Time	-	8 bits
(5) Flags	-	3 bits
(6) Unassigned	-	4 bits

The fourth microprocessor in this group will be used as a binning priority processor to be utilized during periods of high activity. Although as much fully tagged data as possible will be transmitted, the expected count rates during periods of high activity will saturate the tagging system and eventually force a full conversion to binning. The binning priority processor will isolate the most active channels by identifying the high frequency events' tags, both by energy and by pixel, and divert these from tagged data to bins read out at 0.2 second intervals.

As indicated in Figure I-6 the other four microprocessors in the system will serve the following functions:

- (1) Housekeeping and Thermal Control
- (2) Full Sun Monitor and Shutter Control
- (3) Aspect and Pointer Control
- (4) Executive Control, Command and GMT

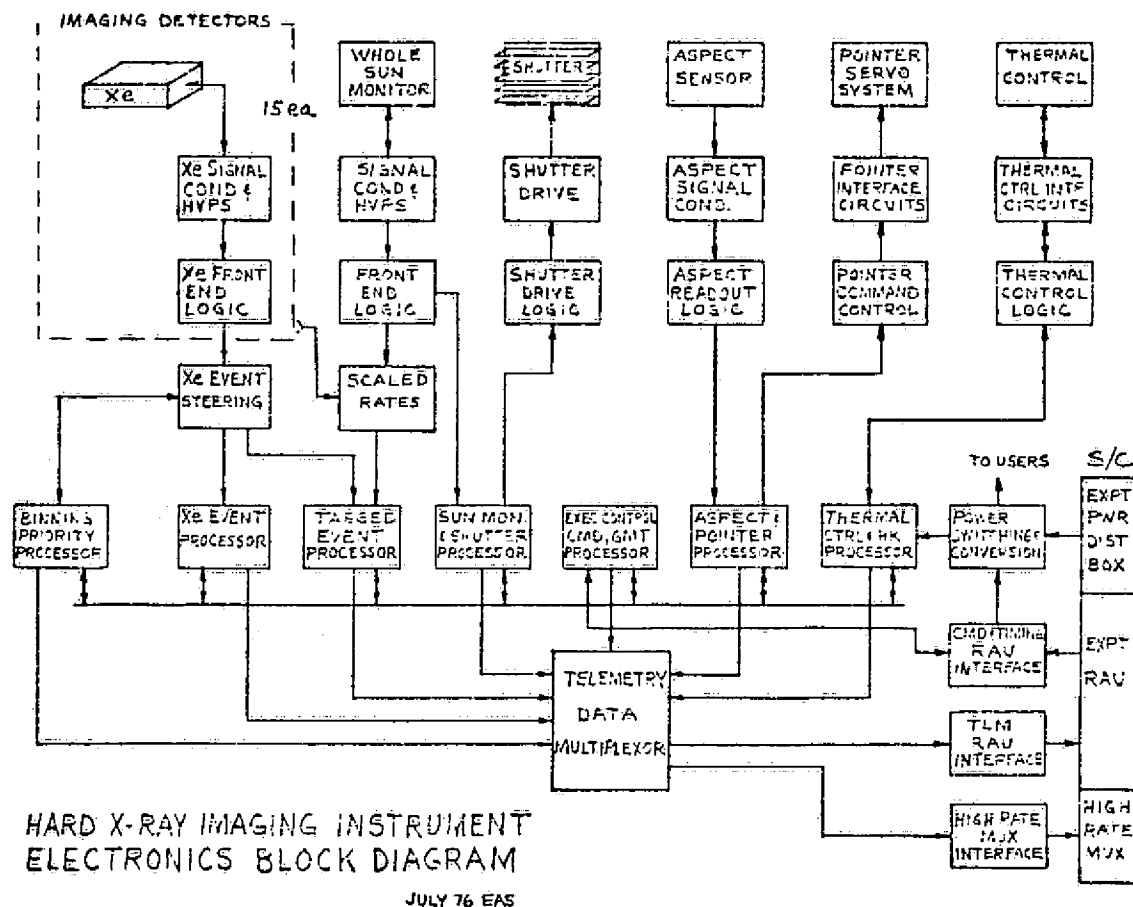


Fig. I-6. Digital electronics for the Hard X-ray Imaging Instrument. Microprocessors play a central role and permit modifications of the software to match the hardware evolution during later Spacelab flights of the instrumentation.

All eight of the microprocessors will be tied together on a common bus and the executive control processor will direct the efforts of the total system.

Interface with the Spacelab Command and Data Management Subsystem (CDMS) is through a Remote Acquisition Unit (RAU). The Spacelab experiment input-output unit will control the distribution of onboard and ground-originated command information as well as timing and Orbiter state vector data to the HXII. The information will be transmitted over the experiment data bus and through the RAU to the instrument. The RAU will also serve as the interface for control data which will be transferred to the experiment input/output unit for formatting in the experiment computer and output

to the display unit at the payload specialist station or to the ground through the 2.0 MBps channels. The control data are currently estimated at between 1.5 kbps and 5 kbps. The high-rate scientific data, which will be in the 100 kbps to 500 kbps range, will be transferred directly to the Spacelab high-rate multiplexer. The transfer will take place over a hard-wire channel which is capable of accepting an input with a bit rate of from 62.5 kbps to 2 MBps.

4. Aspect Systems

(a) Pointing Requirements.

We summarize the instrument pointing in Table I-2. The basic information needed to establish these requirements is the following: (i) the instrument pointing system must be able to point the direct-imaging foveal elements to a given target, implying a setting accuracy of 3 arc sec rms; (ii) the instrument must internally calibrate the co-alignment error between the optical axes of the aspect sensor and the X-ray image; (iii) the instrument pointing system must be capable of pointing with stability ~ 0.4 arc sec rms over a 10 sec interval; (iv) the pointing system must be capable of "dither" motions, for example a circular trajectory with 10 arc sec diameter and 1 sec period; (v) the instrument pointing system must be capable of raster motions and multiple target acquisition within the 40 arc min envelope, and be capable of tracking moving coronal sources over a 5 degree range. These requirements are met either by the Instrument Pointing System (IPS) baselined for SL-2, or by the Small Instrument Pointing System (SIPS) under study by GSFC.

With the optional pointing system we have reduced the pointing requirements as indicated in Table I-2. The optional pointing system accepts input from the Orbiter state vector and sets the telescope to 0.1 degree (rms) precision. Stability of pointing derives from the Orbiter attitude, and the imaging information depends upon accurate aspect-sensing information. Closed-loop operation is also possible for better stability.

(b) Aspect Readout.

The hard X-ray instrument has a large field-of-view envelope; this makes possible the tolerance of a large coalignment error between aspect sensor and X-ray view directions (Table I-2). Precise aspect readout must be achieved, however, at the 0.4 arc sec (rms) level at 0.1 sec intervals, so that re-pointing and image reconstruction may be accomplished to ~ 1 arc sec. Aspect readout devices will be identical for the two pointing-control system options, and exist within the state of the art.

The solar and cosmic observing programs can use a single aspect sensor (for pitch and yaw); this sensor will need a combination of iris diaphragm and neutral-density filter to tolerate the large dynamic range necessary. Accurate registration of the sensor and X-ray axes comes from observation of a known cosmic X-ray point source (e.g. Cyg X-1) and from a solar limb sensor integrally constructed within the grid system. Briefly, this latter device consists of a Fresnel lens mounted on the front grid, and a photodiode sensor mounted on the rear grid. The positions of these devices relative to the actual grid patterns that define the X-ray image are derived by laboratory measurement of the grids.

TABLE I-2

Instrument Pointing

	Instrument Pointing System or Small Instrument Pointing System	UCSD Pointing-Control System
1. <u>Pointing Control System</u>		
Setting Accuracy	3 arc sec (rms) pitch and yaw 10 arc min (rms) roll	0.1 deg (rms)
Pointing Stability	0.4 arc sec (rms) pitch and yaw per 10 sec	Orbiter attitude stability
Motion	"Dither"; raster; tracking (see text) under experiment control	position servo update
2. <u>Aspect Sensors</u>		
Coalignment	4 arc min (rms)	4 arc min (rms)
Tolerance Readout precision	0.4 arc sec (rms) pitch and yaw 80 arc sec (rms) roll	0.4 arc sec (rms) pitch and yaw 80 arc sec (rms) roll

5. Mechanical and Thermal.

(a) Structural.

Maintaining alignment of the multi-grid system places extreme requirements on structural stability, thermal control and grid design. The total error budget for grid spacing is 9μ . Following the conceptual design shown feasible by BBRC (Section II), the baseline configuration is the aluminum truss structure shown in Figure I-2. In this concept a combined metering and integrating structure is used to increase the frontal area. Support to the pointing control gimbal is at the center. Based on a 54-node finite element mechanical model, alignment maintenance in the horizontal position in a 1g field may not be feasible, although the vertical position poses no problem. During an early definition phase, alternate geometrical structural and material approaches will be investigated for feasibility and cost effectiveness.

(b) Grids.

The grid material must have a high atomic number to serve effectively in modulating hard X-rays. Tungsten has been selected for this purpose because of its availability in thin (.001") foils and because it

accepts chemical etching well. A single thickness of this material will suffice for the range of photon energies in this configuration; this eliminates the need for stacking multiple grid layers to obtain sufficient opacity. The etching tolerance of the grids is being met for the SMM experiment because the hole size is virtually identical with that proposed here - the shorter length of the SMM collimator results in 8 arc sec angular resolution, rather than the 4 arc sec of the instrument described here. In other respects, such as size, these grids present less of a technical problem than those presently being fabricated for the SMM. The present concept is to manufacture the grids in $\frac{1}{4}$ quadrant (~ 22 cm) size, and mount 4 of these in a frame ~ 50 cm on a side. These frames will be mounted in the metering structure with precision adjustable locators, for final alignment.

(c) Thermal.

The instrument structure to which the grid elements are mounted also serves as the alignment structure. Static or dynamic thermal distortion of this structure results in grid displacement. If the instrument structure is subjected to a thermal environment for which a temperature gradient exists across the instrument, top to bottom and/or side to side, the relative differential expansion of the instrument structure will result in thermal distortion. A two-stage thermal control system will be required to control the HXII temperatures to the required tolerances. The first stage will limit temperature excursions to $\pm 5^\circ$ C; it will consist of a canister enclosing the entire instrument including front aperture doors. By controlling surface finishes, and adding insulation and heaters to the canister surfaces, the required thermal control can be obtained. A second, internal thermal-control system will bring the temperature gradients into the range of tolerance. Since the thermal canister will be subjected to distortion which could be transmitted to the alignment structure, hard mounting of the instrument to the canister or canister frame is not recommended.

6. Ground Support Equipment

(a) Mechanical.

In addition to the usual handling and transportation fixtures, a hard X-ray imaging system at this and subsequent levels will require an X-ray test facility. This will verify alignment of the grid collimator with X-rays, and permit determination of the detailed angular response of each subcollimator. Briefly, it uses a collimated X-ray beam to verify the collimator response through a series of precisely-controlled translations and rotations.

(b) Electrical.

The electrical checkout system required for the HXII is based on that developed for the UCSD/MIT X-ray and γ -ray telescope on the HEAO-A. This mini-computer based system consists of two component levels: a Module Checkout System (MCS) and an Instrument Checkout System (ICS). The HEAO-A-4 MCS, which tests individual detectors and other systems, could be used

with only minor modifications. The ICS would require update in the form of a Spacelab simulator, a test unit, and more processing power to handle the high bit rates and image reconstruction procedures.

References

- Bradt, H., Garmire, G., Oda, M., Spada, G., Sreekantan, B.V., Gorenstein, P., and Gursky, H., 1968, Space Science Review, 8, 471.
- Datlowe, D.W., Elcan, M.J., and Hudson, H.S., 1974, Solar Physics, 39, 155.
- Oda, M., 1965, Appl. Opt., 4, 143.
- Peterson, L.E., 1975, Ann. Revs. Astron. Astrophys., 13, 423.

SECTION II

SCIENTIFIC OBJECTIVES

FOR A

HARD X-RAY IMAGING INSTRUMENT

PART II

SCIENTIFIC OBJECTIVES

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I. INTRODUCTION

The ability to accelerate particles to high energies appears to be a property of many plasmas of astrophysical interest. The aurora, solar and stellar flares, X-ray stars, pulsars, supernovae, radio galaxies and quasars all exhibit strong non-thermal effects. Transient cosmic γ -ray bursts and galactic cosmic rays also clearly involve particle acceleration, and the magnetospheres of Earth and Jupiter offer additional examples. Imaging observations of X-ray and γ -ray emissions from these objects will provide new and fundamental information on the acceleration mechanisms, the energy storage and release by the particles, and their coupling to magnetic fields and thermal plasmas in the sources.

The study of particle acceleration in the universe therefore represents the main scientific objective of hard X-ray imaging observations. In this chapter we discuss specific observations in some detail. In the case of solar particle acceleration, hard X-ray imaging will provide quantitative data that will test relatively well-worked-out models. The non-solar observations give access to a wider variety of astrophysical environments; they will provide answers to some questions already asked, but they will also be expected to produce new discoveries in as yet unexpected areas. In a sense the cosmic X-ray observations are more exploratory.

II. SOLAR OBSERVATIONS: PARTICLE-ACCELERATION PROCESSES RELATED TO SOLAR FLARES

Among the non-thermal phenomena in the universe, solar flares provide particularly easily studied cases of particle acceleration: flares accelerate particles to relativistic energies; the solar plasmas occur close enough to the Earth to permit sufficiently high spatial resolution, but do lie far enough away for a global view of their structures. The energetic particles dominate the energy content of many flares, so that the understanding of their acceleration constitutes an important step in clarifying the flare processes themselves. Svestka (1976) has given a recent comprehensive review.

A. Present Status of Knowledge

Our present knowledge of solar particle-acceleration processes has come primarily from the observations of solar hard X-ray and radio emission, and from direct observations of the accelerated particles released into the interplanetary medium. The X-ray bremsstrahlung radiation process is relatively simple and well-understood compared to the processes of radio emissions and absorption, and the particle escape and propagation. Thus most of the quantitative information about non-thermal electrons at the Sun has been obtained from the interpretation of the hard X-ray measurements. Direct interplanetary particle observation and γ -ray line measurements provide information on the acceleration of protons and nuclei, but low sensitivity for γ -ray lines has permitted observations of only two very outstanding flare events. Most of the remaining phenomena relevant to

particle acceleration processes at the Sun are those which result from the deposition of the kinetic energy of the accelerated particles, through collisions, in the solar atmospheric gas. These include white-light emission, $H\alpha$ kernels, rapid soft X-ray flare brightenings, EUV flashes, etc. The main advantages of these types of observations are the clues they give toward locating the accelerated particles at the Sun, determining the time scales of the acceleration, and the nature of the particles.

Observations at ground level of secondary mesons and neutrons made as early as 1942 provided the first evidence for the existence of very energetic "solar cosmic rays". Since 1956 riometers have measured the ionospheric effects of energetic protons in the polar cap regions of the Earth. Nowadays direct spacecraft measurements, as well as ground-based observations, provide means of studying the products of the acceleration processes responsible for the energetic particles. The information gleaned from particle observations remote from the Sun is limited by our uncertainties regarding the propagation of the particles, and regarding the magnetic structures in the lower corona.

The radio observations have revealed the presence of a wide variety of phenomena occurring in the solar chromosphere and corona. The high brightness temperatures and rapid fluctuations observed for many types of solar radio bursts leave little doubt that they are due to non-thermal processes involving energetic electrons. From type III bursts we learn that in some instances the acceleration time for 10-100 keV electrons can be ~ 1 sec and that the acceleration process is highly repetitive. Observations by the Culgoora radioheliograph show coronal acceleration, to higher electron energies, occurring over very wide regions as the result of shock-wave passage through the corona. The continual stormy radio-burst activity of some active regions, even in the absence of flares, suggests that electron acceleration occurs on a continuous basis in some parts of the Sun.

The radio observations in general have high sensitivity and good spatial and temporal resolutions; in addition the wide range of available wavelengths lets us probe the entire depth of the solar corona and chromosphere. The radio emissivity and propagation of the radiation, however, depend strongly upon the local plasma conditions, and vary greatly with changes in density and magnetic-field structure. This makes it difficult to obtain quantitative information from radio observations without knowing the detailed structure of the solar atmosphere in an active region.

Since the X-ray and γ -ray fluxes observed during solar flares come directly from collisions of the non-thermal particles with ambient particles, the interpretation of the X-ray and γ -ray spectra is relatively simple, and allows some reasonably quantitative inferences about the energetic processes. The X-ray observations show that 10-100 keV electron acceleration occurs commonly in solar flares and that the accelerated electrons above ~ 20 keV contain a substantial, and sometimes dominant, portion of the total flare energy. The non-thermal spectrum will contain even more energy below 20 keV, but observations below this energy tend to be confused by the very strong thermal X-ray emission from the $\sim 2 \times 10^7$ °K flare plasma.

The electron energy spectrum inferred from the X-ray observations usually fits a power law in energy, but frequently exhibits a steepening above ~ 50 keV. For a small flare the duration of the acceleration process obtained from the X-ray observations is typically $\sim 10^2$ seconds, but the overall event appears to be made up of short bursts of acceleration on < 1 -10 second time scale. The true time scale of the acceleration may be even shorter, but current X-ray instrumentation is limited in temporal resolution to ~ 1 second.

Observations in the interplanetary medium provide a direct sample of accelerated electrons. Comparisons of the escaping electrons and X-ray emitting electrons indicate that the acceleration region is located in the lower corona, and that generally only a small fraction of the accelerated electrons escape. The presence of energetic electrons at all times in the near-Earth interplanetary medium, even though the solar wind is always sweeping them out of the inner solar system, suggests that the Sun may be quasi-continuously accelerating these particles. Another indication for this is the observation of many type III radio bursts on the Sun that are not flare-associated and do not coincide in time with hard X-rays. Nevertheless they still represent streams of accelerated electrons in the corona.

While the acceleration of electrons is intimately associated with hard X-rays, impulsive microwave bursts and radio type III bursts, the acceleration of nuclei appears to have a strong association with shock waves. Type II and moving Type IV radio bursts accompany proton flares, and protons are observed to be accelerated in front of the interplanetary shocks. In addition the acceleration of electrons to relativistic energies is observed to accompany the acceleration of nuclei. The smaller electron fluxes may indicate a rigidity-dependent injection into the acceleration process. This is what one would expect from stochastic acceleration processes associated with shock waves.

In summary, we know of at least two distinct acceleration processes in solar flares: one, quite common, that is a highly efficient accelerator of electrons (and perhaps protons) to $\sim 10^2$ keV energy and which must be closely related to the solar flare mechanism itself. A second process follows the first one in some particular flares and accelerates both protons and other nuclei, as well as electrons, to MeV and even GeV energies. The latter process is apparently able to duplicate the galactic cosmic-ray acceleration mechanism at low energies. The primary acceleration mechanism must be closely related to the conversion of magnetic energy into flares. The acceleration to higher energies may be linked to the presence of flare-induced shock waves in the solar atmosphere and interplanetary medium.

Still a third acceleration mechanism may operate on the Sun, giving rise to the electron streams producing the type III radio bursts. Such bursts occur mostly without flares, but do tend to coincide in time with the above-mentioned primary acceleration process when a flare occurs in a type III-producing active region. Future observations may therefore reveal the identity of the impulsive-phase and type-III burst acceleration mechanisms, or may establish their fundamental difference.

B. Hard X-ray Imaging Applied to Solar Particle Acceleration

In the following sections we discuss several specific problems and indicate the role of hard X-ray imaging in their solutions. We have divided the discussions into two major subsections, for the impulsive and coronal phases of flares. For each phenomenon discussed we have estimated the parameters of the expected X-ray sources, on the basis of theoretical arguments depending upon existing radio and X-ray observations. Table 1 summarizes these estimates.

1. Impulsive Phase.

(a) Where within the flare structure does the primary acceleration take place?

The acceleration of 10-100 keV electrons during the impulsive phase requires a large fraction (up to 10^{32} ergs greater than 20 keV) of the total flare energy (Lin and Hudson, 1971; 1976). The most urgent problem in understanding this energy release lies in determining precisely where it occurs within the large-scale structure of the flare. Several theories propose macroscopic instabilities that should give recognizable characteristics to the hard X-ray images, as discussed below. Because X-radiation directly shows energy-loss regions, rather than acceleration regions, we must relate the observations to the theories through extensive correlated observations and detailed model-building for the flaring plasmas.

The short duration (1-100 sec) of hard X-ray and microwave bursts associated with the impulsive phase (Kane and Anderson, 1970; Datlowe et al., 1974b) suggests small size scales. The only direct X-ray information has come from the observation of a single flare by Takakura et al. (1971) with a balloon-borne X-ray telescope resembling the instrument defined in this report; this observation yielded an upper limit of about 1 arc min. The best inference on the location and size of the hard X-ray source during the impulsive phase of a flare comes from observations of white-light flares (Svestka, 1970; McIntosh and Donnelly, 1972). An example, for the white-light flare of August 7, 1972 (Rust and Hegwer, 1975), is illustrated in Fig. II-1. The white-light emission occurred in four patches of brief duration (about 5 sec) and small size (2-4 arc sec); the grid in Figure 1 shows the angular resolution and field of view of the imaging instrument described later, relative to the white-light structures. Similarly small, rapid brightenings tend to appear in H α (Vorpahl, 1972) and similar effects have been noted at λ 3835 Å (Zirin and Tanaka, 1973). The association of these phenomena, especially the white-light continuum brightening, with energetic particles now seems well established (Svestka, 1970; Najita and Orrall, 1970; Hudson, 1973; see also Svestka, 1976 for a full discussion). On this basis we expect to see multiple bright points in the hard X-ray image, with size scales on the order of a few arch seconds.

These observations will directly test the thick-target model, in which the electrons lose a substantial fraction of their energy to collisions and thereby support secondary phenomena (Lin and Hudson, 1971, 1976). If the hard X-rays come from lower altitudes with higher densities, then the thick-

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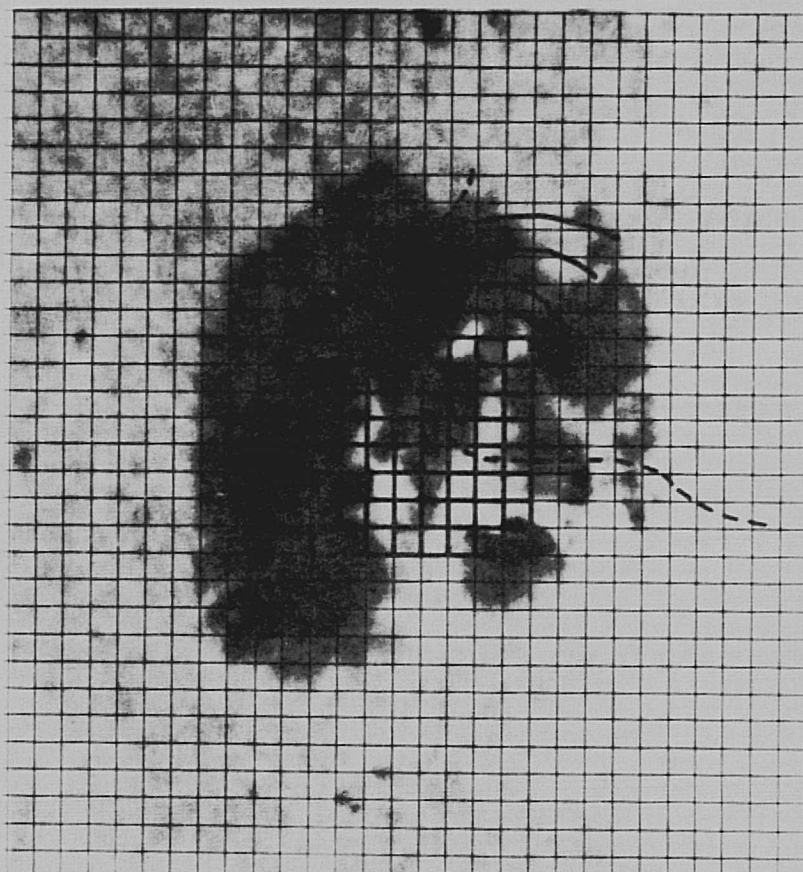


Figure II-1. White-light observations of the Aug. 7, 1972 flare. These observations (Rust and Hegwer, 1974) show four emission patches on opposite sides of the neutral line of the longitudinal magnetic field, as indicated by the dashed line. Scale is indicated by a 4 arc sec grid; North is at the top. The white-light patches correspond to the feet of magnetic loops, and should also be bright in hard X-radiation according to the thick target model.

target model must hold. On the other hand, if the hard X-ray sources are diffuse and extend into the corona, then we must have thin-target emission; the electrons escape to the corona with negligible energy loss. We expect the latter case to hold for many coronal phenomena, following the OSO-5 (Frost and Dennis, 1971) and OSO-7 (Roy and Datlowe, 1975) observations of over-the-limb flares.

(b) What is the relationship between non-thermal processes and the hot flare plasma?

The geometry of the soft X-ray emission has now become clear as a result of the Skylab observations: loop or arch structures appear to confine the hot plasma ($T \sim 10^7$ K) (Kahler et al., 1975; Vorpahl et al., 1975). These structures show the locations of the coronal magnetic flux tubes that participate in the flare (Widing and Cheng, 1974). The hard X-ray burst that defines the impulsive component correlates in time with the growth of these hot loops (Datlowe et al., 1974a), which may have sizes of 30-40 arc sec; we therefore expect to see the hard X-ray image identified with certain parts of the soft X-ray sources: the feet of magnetic loops, the tops of these loops, or whole distinct (smaller?) loops. Each of these possibilities involves certain mechanisms for driving plasma to a superheated condition. To place the observations proposed here into the proper perspective, Fig. II-2 shows the June 15, 1973 flare observed by the Skylab (Widing and Cheng, 1975); these observations show small loop-like structures in a Fe XXIV line, indicative of the hottest part of the flare.

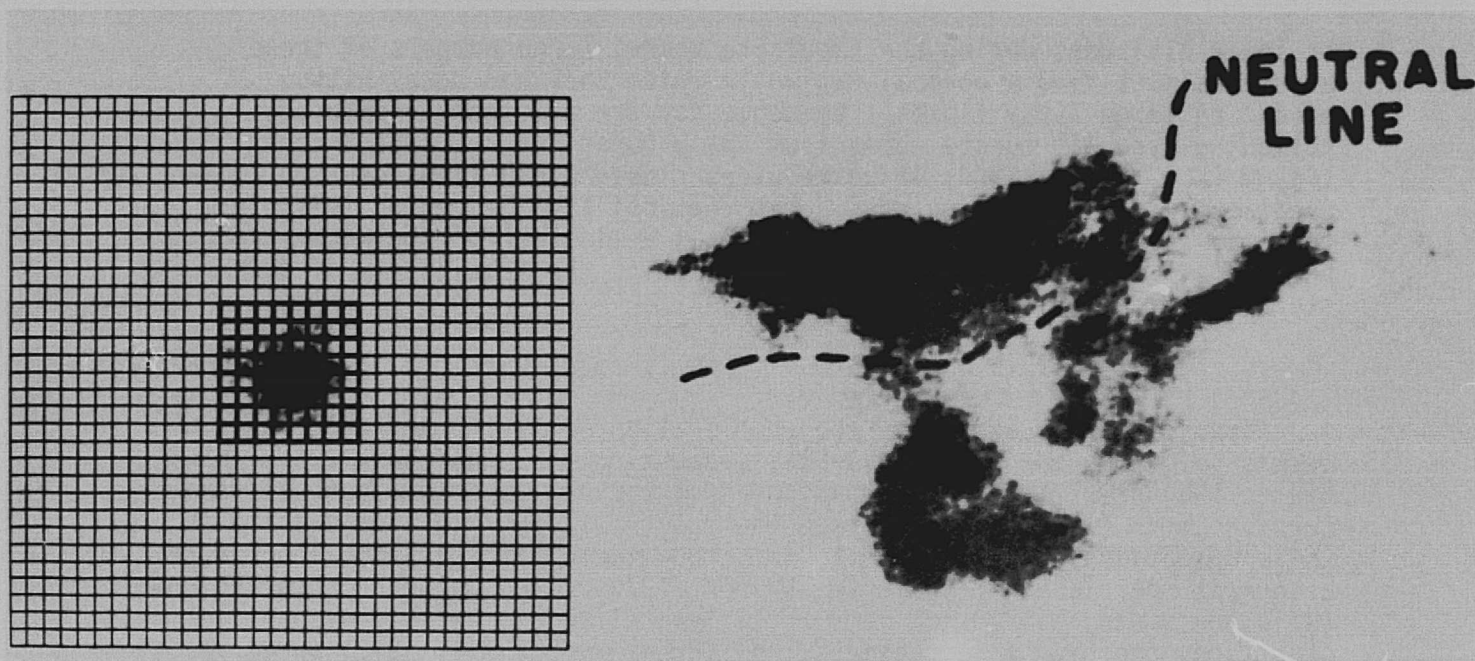
(c) What is the relationship of Type III burst particle acceleration to the impulsive phase?

The Type III radio burst first appears at a high frequency (100-500 MHz) and rapidly drifts toward lower frequencies. The accepted interpretation (e.g. Wild et al., 1963) in terms of 10-100 keV electron streams moving outward in the solar corona has been confirmed by direct interplanetary observation of the electrons (e.g. Lin, 1974), but the relationships of Type III bursts to the impulsive phase is confusing. We often observe a close time coincidence (Kane, 1972; McKenzie, 1972) between the occurrence of the Type III burst and the hard X-ray burst; in many other cases the Type III burst may occur even in the absence of any recognizable flare. Establishing the relationship between the Type III burst electron population and the impulsive phase electrons therefore becomes very interesting - are there indeed two separate instabilities that act simultaneously, or can some impulsive-burst electrons "leak" from the common acceleration site to produce some of the Type III bursts?

2. Coronal Phase.

(a) Is there coronal trapping of 10-100 keV electrons?

Coronal storage of non-thermal electrons must result if thin-target models of the hard X-ray emission hold; we know from interplanetary observations that the impulsive-phase electrons do not escape freely into the interplanetary medium. Thus, subsequent to their interactions



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Figure II-2. Skylab observations of the June 15, 1973 flare with the NRL slitless spectrograph (Widing and Cheng, 1974). Two images appear: Fe XXIV on the left, with the 4 arc sec grid superposed, and He II on the right. The direction of dispersion is left-right, and the wavelength difference is such that the Fe XXIV brightening falls on the neutral line between the He II ribbons. This implies a hot loop with cold feet; the loop should be visible in soft X-ray continuum and should have a definite model-dependent relationship with hard X-ray brightenings.

at lower altitudes during the impulsive phase, large numbers of these electrons must find a coronal region in which they can decay without producing large X-ray fluxes. Evidence for the existence of storage following Type III bursts comes from the U-burst and the Type V continuum (e.g. Kundu, 1965) which requires closed field lines of great extent. Table II-1 includes a hypothetical storage region following the impulsive phase of a flare, as well as estimates for the known radio phenomena. Little theoretical work concerning the feasibility of such storage regions exists (cf Anderson, 1972).

(b) What is the nature of Type II burst particle acceleration?

Type II bursts accompany the acceleration of 10-100 keV electrons in bursts (e.g. Sheridan et al., 1959), suggesting that the shock front initiates the normal Type III mechanism as it traverses various coronal features. Smith (1972) has discussed the theory of particle acceleration in these conditions. In addition to this non-thermal process, the shock must also heat the plasma it traverses (Hyder, 1970). The Culgoora observations (Wild and Smerd, 1972) show very large Type II sources with considerable structure; the hard X-ray observations (Frost and Dennis, 1971) agree in time quite well. Imaging of hard X-rays with low resolution (about 1 arc min) will identify the coronal structures involved in particle acceleration. Additionally the Type II bursts accompany the second-stage acceleration process for >1 MeV energies, since Type II occurrence correlates with high-energy protons in space (Svestka and Fritzova, 1967).

(c) What is the nature of Type IV burst particle acceleration?

The meter-wave Type IV bursts, as observed at Culgoora (Wild and Smerd, 1972), represent the synchrotron radiation of MeV-range electrons. The hard X-ray detectability of these electrons depends crucially upon their number and the ambient density, and the radio observations do not lead to reliable estimates of these numbers. Taking for example the results of Ramaty and Lingenfelter (1968) for one event, we have $\sim 10^{34}$ electrons with $E_e \sim 2.5$ MeV at $n_i = 3 \times 10^7 \text{ cm}^{-3}$. If we assume a power-law distribution with index 3, below 2.5 MeV, then we compute a 20 KeV X-ray flux of $\sim 10^2$ photons $(\text{cm}^2 \text{ sec keV})^{-1}$. This very large flux agrees approximately with the flux level observed by TD-1A in the August 1972 flares (van Beek, 1974): if the electrons emitting these X-rays actually do so at such a low density, then a hard X-ray imaging system would be able to observe very large volumes of the corona. Fig. II-3 shows as an example the moving Type IV burst on March 1, 1969 (Riddle, 1970), with the 1 arc min grid of the coarse fan beams indicated. A similar calculation to that above for Riddle's data ($n_i = 10^6 \text{ cm}^{-3}$, $E_e = 0.75$ MeV, $N = 10^{32}$ electrons) gives a 20 keV flux of $\sim 3 \times 10^{-3} (\text{cm}^2 \text{ sec keV})^{-1}$. This refers to a source position at $5 R_\odot$, and we would expect much larger fluxes nearer the sun. Both of these estimates result from exceptionally large events but the fluxes lie well within the range of feasibility.

The utility of hard X-ray observations of such phenomena lies in the entirely new perspective they give. Where the X-radiation depends on density alone, the synchrotron flux depends upon both density and magnetic field

Table II-1

Properties of Solar Hard X-Ray Bursts

Phenomenon	Source Region Density (cm^{-3})	Number of Electrons (20 keV)	X-Ray Flux at 20 keV ($\text{ph}/\text{cm}^2\text{-sec-keV}$)	Duration (sec)	Diameter (arc min)
Impulsive Burst*	10^{10-13}	10^{34-40}	$<10^{-1}-10^2$	$1-10^3$	<1
Storage Region**	$<10^7$	10^{34-40}	<0.1	10^{4-5}	large
Type II	?	?	?	$\sim 10^3$	large
Type III	10^9	10^{31-34}	$10^{-4}-10^{-1}$	≤ 1	<2
Type IV	10^{6-8}	10^{32-38}	$10^{-4}-10^2$	$\sim 10^3$	5-15

* These numbers represent typical ranges for observed impulsive hard X-ray burst (e.g. Datlowe et al. 1974b), interpreted on a thick-target model.

** The storage region is hypothesized to exist after a thin-target impulsive burst.

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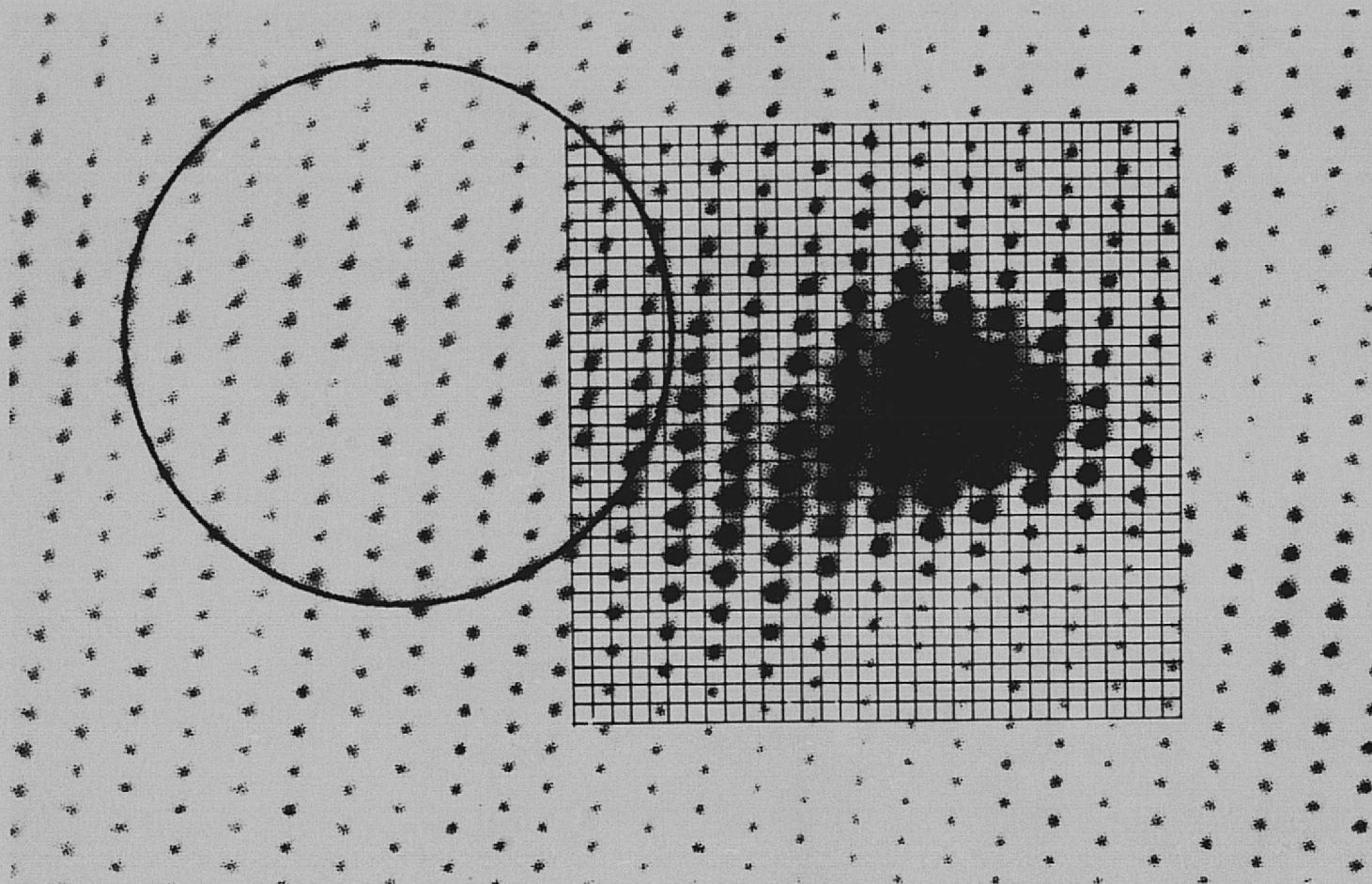


Figure II-3. Culgoora observations (80 MHz) of a moving Type IV burst at 2317 UT, March 1, 1969 (Riddle, 1970) with a one arc min grid superposed to indicate the angular scale. North is at the top, West to the right; the circle represents the location of the solar disk. The electrons that produce gyro-synchrotron radio emission should also emit hard X-radiation through bremsstrahlung as estimated in the text.

strength. Successful hard X-ray imaging observations will therefore help determine values for the coronal magnetic field in the regions. Mapping the source distribution alone will immediately determine the configuration of the plasmoid or loop structure causing the Type IV burst, and knowledge of the geometry will allow a choice from among the various models proposed (e.g. Wild and Smerd, 1972).

(d) What is the geometry of open field structures in the corona?

Various population of energetic particles may serve as tracers of open as well as closed field lines in the corona; normally such lines (e.g. in the coronal holes) do not contain enough material to produce measurable radiation. Fast electrons accelerated in or after solar flares will mark these magnetic structures; in particular Type III bursts (see above) may illuminate field lines directly connecting the interplanetary medium with the flare site.

C. Summary

The information provided by a hard X-ray imaging instrument can aid in describing the location of the solar acceleration processes, at several levels. In the most elementary configuration of the instrument (see Section I for a full description) the measurement of size and shape of the hard X-ray component alone will be of great value. Still better is the simultaneous observation of soft X-ray structures, and the relative position of the hard X-ray sources associated with them. Finally, the optimum degree of information would come from the absolute position of hard and soft X-ray structures permitting detailed analysis of the magnetic field, white-light, and H α configurations near the X-ray flare.

III. IMAGING OBSERVATIONS OF COSMIC HARD X-RAY SOURCES

Imaging of cosmic X-ray sources represents the next substantial step in high energy astrophysics after the exploratory observations by OSO's, Uhuru, SAS-C and other satellites. Following the deep survey by the HEAO-A, the HEAO-B will carry a large focussing telescope for imaging soft ($E < 4$ keV) X-rays. The principal observation results will be (i) the identification of X-ray point sources with objects visible at other wavelengths, which greatly aids in understanding the astrophysics of these sources; and (ii) the mapping of thermal and non-thermal X-ray structures within extended sources. A hard X-ray imaging system will permit these studies to be carried out over a broad energy range, in particular into the 10 - 30 keV region, where thermal and non-thermal processes are clearly distinguished in some classes of objects.

A. Activation of the Crab Nebula

The pulsar NP 0532 apparently supplies the energy observed to be radiated from the entire volume of the nebula. A map of the hard X-ray emission will provide information about the transport of energy from the pulsar, the acceleration of particles within the nebula, and the subsequent propagation of these particles.

Energetic particles in the Crab Nebula penetrate throughout its visible extent, as inferred from their synchrotron emission. Recently Ricker et al. (1975) confirmed at higher energies the observation of Bowyer et al. (1964) of a large angular size for the X-ray source. The exact relationship between the accelerated particles and the pulsar has become far less clear since the recent observations revealed a displacement between the X-ray source and the pulsar (Ku et al., 1976). Figure II-4 shows the hard X-ray source superimposed on a polarized-light image described by Scargle (1969). The feature Scargle termed "Wisp One" seems closer to the center of the X-ray source; this diffuse object may undergo time variations in conjunction with glitches in the pulsar rate of slowing down (Scargle and Harlan, 1970). Higher angular resolution will resolve Wisp one and other optical features, and thus reveal their role in the particle acceleration.

B. Clusters of Galaxies

Clusters of galaxies contain extended X-ray sources now known. The Perseus cluster Fig. II-5 showing the coarse-resolution grid) provides a good example: an extended, thermal source. It contains embedded within it a compact source centered on the Seyfert galaxy NGC 1275; a bar of emission also extends from NGC 1275 toward the radio tail galaxy IC 310 (Wolff et al., 1973). Recent spectral observations of the Fe XXIV-Fe XXV line complex (Mitchell et al., 1976; Serlemitsos et al., 1977) in the Perseus, Coma and Virgo clusters virtually confirm a thermal model for the extended source. Especially regarding the iron lines, this will give information on the evolution and elemental enrichment of the gas. Hard X-ray imaging may also reveal the presence of diffuse halos (few arc sec) around compact sources in clusters of galaxies. If so, this would provide evidence for the escape of non-thermal electrons into the intra-cluster medium.

C. Identification of Extragalactic Compact Sources

Individual extragalactic sources, including QSO's, radio galaxies and Seyfert galaxies, have been detected at X-ray energies. These objects have extremely hard spectra; NGC 4151, a Seyfert galaxy, has a flat power-law extending to ≥ 100 keV (Baity et al., 1975; Pacias et al., 1976) as does the radio galaxy Cen A (Lampton et al., 1972; Mushotzky et al., 1976; Hall et al., 1976). In addition a high low-energy cutoff (about 3 keV) is associated with this object. A hard X-ray telescope can thus locate such sources accurately to permit identification of optical or radio counterparts. Fig. II-6 shows such an application in Cen A; here we ask whether the hard X-ray sources coincide with the nucleus, with the inner radio lobes, or with the other apparent ejecta (Blanco et al., 1975). Identification of the X-ray source then leads to full development of the physics via related radio and optical observations. In Fig. II-7 we see the giant elliptical galaxy M87 (Virgo A) showing the ability of a 4 arc sec angular resolution to resolve the jet from the nucleus.

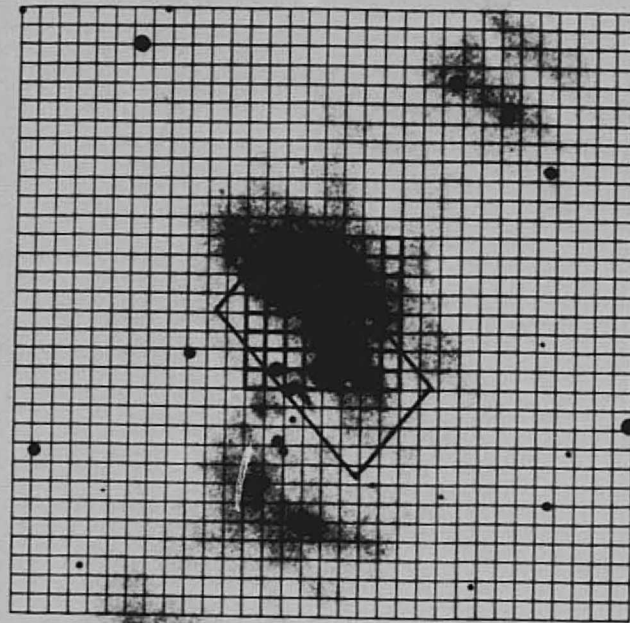


Figure II-4. Crab Nebula in polarized light (Scargle, 1969), North at the top, East to the right. The picture shows the pulsar NP0532 as the S of the two stars within the rhombus indicating the MIT lunar occultation measurement (Ricker et al., 1975). The "wisps" can be seen near the pulsar. The square grid shows a 4 arc sec angular scale.

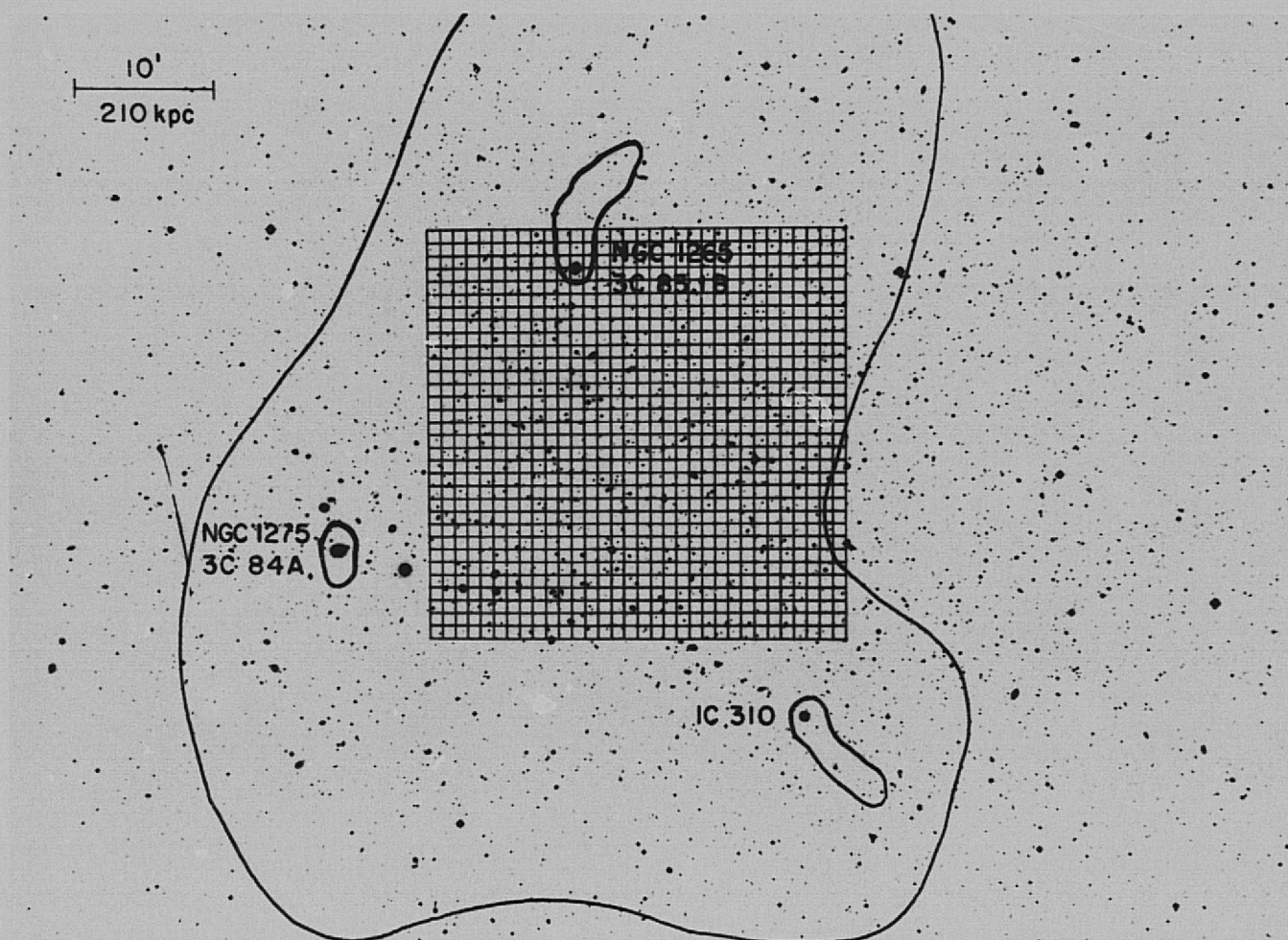
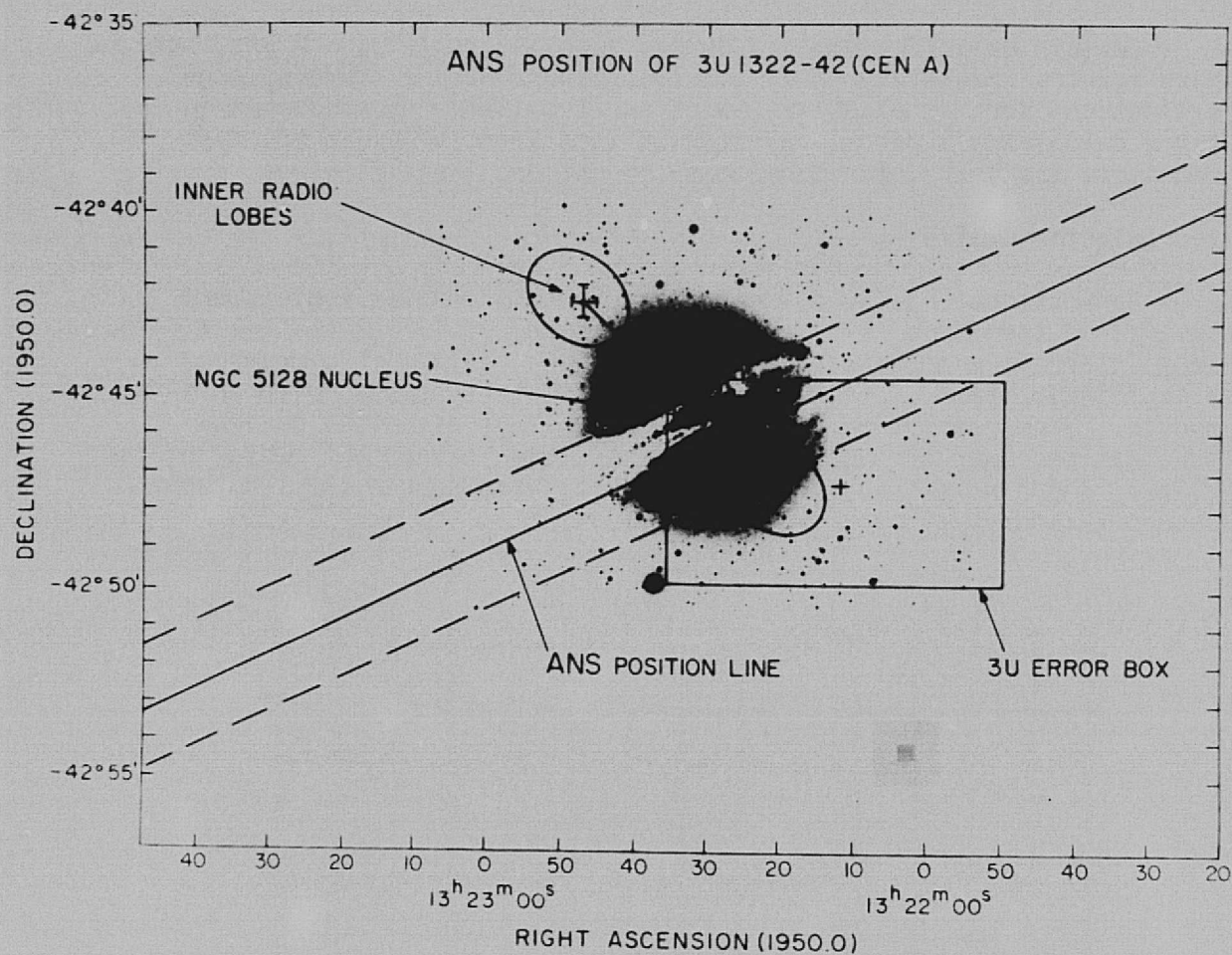


Figure II-5. Perseus cluster of galaxies, with 1 arc min grid. The outer contour represents the radio source 3C 84. The soft X-ray source seems to consist of a large diffuse source, a point source centered on the Seyfert galaxy NGC 1275, and a bar of emission matching the line of galaxies reaching from NGC 1275 to the radio tail galaxy IC 310.



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Figure II-6. Optical/radio/X-ray map of Cen A (Grindlay et al., 1975). The grid at lower right represents a 2 arc min array of the 4 arc sec image elements shown in the earlier figures. The inner radio lobes, as well as the nucleus, are potential hard X-ray sources from Compton scattering.

D. Galactic Compact Sources

Certain galactic compact sources such as Cyg X-1 and X Per, have hard spectra (Mushotzky et al., 1977); others have extremely large extinction, such as GX 301-2 (Swank et al., 1976). For sources in these categories a hard X-ray imaging instrument provides the most sensitive discovery, position measurement, and identification.

E. Galactic Center

Many discrete X-ray sources exist in this complex region, and several of them have hard spectra. Of these, 3U 1728-24 (=GX 1 + 4) has very interesting properties (Davidson et al., 1977): it appears to be a "symbiotic star", a rare association of late-type star with an X-ray source. High-resolution imaging in hard X-rays gives the maximum penetrating power through the large extinction toward the center of the Galaxy, where an extended (about 2°) soft X-ray source (3U 1743-29) occurs (Giacconi et al., 1974).

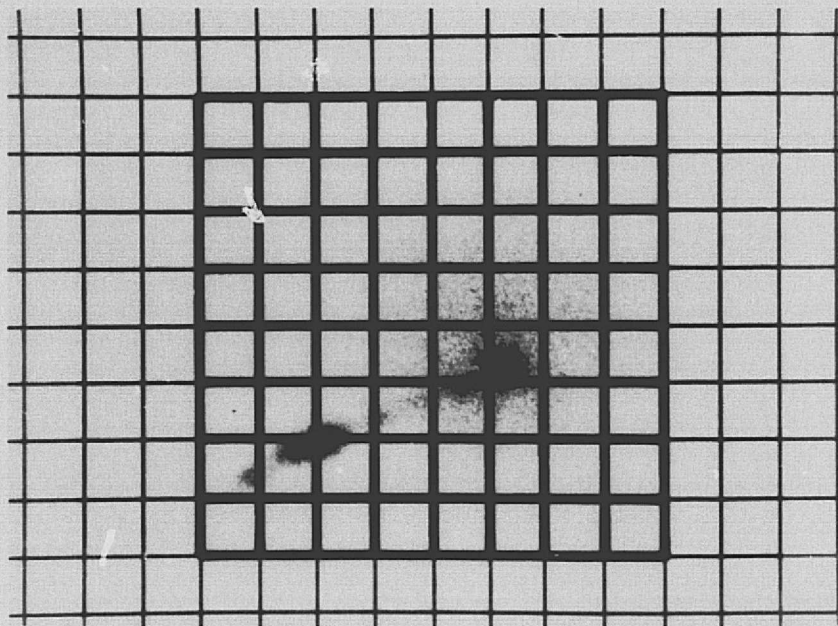


Figure II-7. Optical image of the central region of the elliptical galaxy M87 (radio source Virgo A), with a 4 arc-sec grid superimposed. The "jet" extending to the west of the nucleus consists of a series of blobs visible in synchrotron radiation.

F. Summary

The cosmic observations are a good deal more exploratory than the solar observations, with well-defined exceptions as mentioned above. Little can be predicted regarding the unidentified high-latitude sources in the Uhuru catalog, for example. We will wish to optimize the hard X-ray telescope configuration for observations of other classes of sources, as we obtain data in early flights of the instrumentation. As an example, one class of optimization would consist of devoting maximal area in unique fan beams; this would be ideal for position determination and identification with a hard X-ray imaging instrument representing a natural step after HEAO-A (hard X-ray source discovery) and HEAO-B (soft X-ray source imaging). We note especially the complementary nature of the spectral ranges of a grid-collimator telescope (λ 2 keV) and a grazing-incidence focusing telescope (λ 4 keV) such as that on HEAO-B; the techniques permit comparable angular resolutions.

Both solar and non-solar observations relate to different aspects of the same problem area: non-thermal particle acceleration. As long as the instrumentation need not be optimized for one kind of observation, to the exclusion of the other, it will reward us to do both. Finally, we should remark upon the planetary aspects of hard X-ray imaging: the terrestrial aurora and the magnetospheres of the outer planets. Both of these represent difficult observational problems, but they must also be kept in mind during the evolution of the study of non-thermal particles in astrophysics, via their X-ray and γ -ray emissions.

References

- Anderson, K.A. 1972, Solar Phys., 27, 442.
- Antiochos, S., and Sturrock, P.A. 1977, Solar Phys., to be publ.
- Baity, W.A., Jones, T.W., Wheaton, W.A., and Peterson, L.E. 1975, Ap. J. (Letters), 199, L5.
- Blanco, V.M., Grahm, J.A., Lasker, B.M., and Osmer, P.S. 1975, Ap. J. (Letters), 198, L63.
- Bowyer, S., Byram, E.T., Chubb, T.A., and Friedman, H. 1964, Science, 146, 912.
- Bracewell, R., and Riddle, A.T. 1968, Ap. J., 150, 427.
- Chupp, E.L., Forrest, D.J., Higbie, P.R., Suri, A. N., Tsai, C., and Dunphy, P.P. 1974, Nature, 241, 333
- Craig, I.D., and McClymont, A.N. 1976, Solar Phys., 56, 133
- Datlowe, D.W., Hudson, H.S., and Peterson, L.E. 1974a, Solar Phys., 35, 193.
- Datlowe, D.W., Elcan, M. J., and Hudson, H.S. 1974b, Solar Phys., 39, 155.
- Davidson, A., Malina, R., and Bowyer, S., 1977, Ap. J., 211, 866.
- Dicke, R.H. 1968, Ap. J., 163, L101.
- Frost, K.J., and Dennis, B.R. 1971, Ap. J., 165, 655.
- Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky, T., Koch, D., and Tananbaum, H. 1974, Ap. J. Suppl., 27, 37.
- Gursky, H., Solinger, A., Kellogg, E.M., Murray, S., Tananbaum, H., and Giacconi, R. 1972, Ap. J. (Letters), 174, L99.
- Hall, R.D., Meegan, C.A., Walraven, G.D., Djuth, F.T., and Haymes, R.D. 1976, preprint.
- Hudson, H.S. 1973, in High Energy Phenomena on the Sun, R. Ramaty and R.G. Stone (eds.) (NASA SP-342), 207
- Hyder, C. 1970, Solar Phys., 14, 196.
- Kahler, S.W., Krieger, A.S., and Vaiana, G. S. 1975, Ap. J. (Letters), 204, L77.

- Kane, S.R., and Anderson, K. A. 1970, Astrophys. J., 162, 1003.
- Kostyuk, N.D. 1975, Sov. Ast., 19, 458.
- Kundu, M.R. 1965, Solar Radio Astronomy, New York, Interscience.
- Ku, W., Kestenbaum, H.L., Novick, R., and Wolff, R. 1976, Ap. J. (Letters), 204, L77.
- Lampton, M., Margon, B., Bowyer, S., Mahoney, W., and Anderson, K. 1972, Ap. J., 171, L85.
- Laros, J.G., Matteson, J., and Pelling, R.M. 1973, Nature Phys. Sci., 246, 109.
- Lin, R.P., and Hudson, H.S. 1971, Solar Phys., 17, 412.
- Lin, R.P., 1974, Space Science Reviews, 16, 189.
- Lin, R.P., and Hudson, H.S. 1976, Solar Phys., 50, 153.
- McIntosh, P.S., and Donnelly, R.F. 1972, Solar Phys., 23, 444.
- McKenzie, D.L. 1972, Ph. D. Thesis (UCSD).
- Mitchell, R.J., Culhane, J.L., Davidson, P.J.N., and Ives., J.C. 1976, Mon. Not. R. Astron. Soc., 176, 29.
- Mushotzky, R.F., Baity, W.A., Wheaton, W.A., and Peterson, L.E. 1976, Ap. J., 207, L45.
- Mushotzky, R. F., Roberts, D.H., Baity, W.A., and Peterson, L.E. 1976, Ap. J., 207, L45.
- Najita, K., and Orrall, F. Q. 1970, Solar Phys., 15, 176.
- Paciesas, W.A., Mushotzky, R.F., and Pelling, R.M. 1977, Mon. Not. Roy. Ast. Soc., 178, 23p.
- Ramaty, R., and Lingenfelter, R.E. 1968, Solar Phys., 5, 531.
- Rappaport, S., Cash, W., Doxsey, R., Moore, G., and Broken, R. 1973, Ap. J. (letters), 186, L115.
- Ricker, G.R., Scheepmaker, A., Ryckman, S.G., Ballintine, J.E., Doty, J.P., Downey, P.M., and Lewin, W.H.G. 1975, Ap. J., 197, L83.
- Riddle, A.C. 1970, Solar Phys., 13, 448.
- Roy, J.R., and Datlowe, D.W. 1975, Solar Phys., 40, 165.

- Rust, D.M., and Hegwer, F. 1975, Solar Phys., 40, 141.
- Scargle, 1969, Ap. J., 156, 401.
- Scargle, J.D., and Harlan, E.A. 1970, Ap. J. (Letters), 159, L143.
- Serlemitsos, P.J., Smith, B.W., Boldt, E. A., Holt, S.S., and Swank J.H., 1977, 211, L63.
- Sheridan, K.V., Trent, G.H., and Wild, J.P. 1959, The Observatory, 79, 51.
- Smith, D.F. 1972, Ap. J., 174, 643.
- Svestka, Z. 1970, Solar Phys., 13, 471.
- Svestka, Z. 1976, Solar Flares (Dordrecht: D. Reidel).
- Svestka, Z., and Fritzova, L. 1967, Solar Phys., 2, 75.
- Swank, J.H., Becker, R. H., Boldt, E.A., Holt, S.S., Pravdo, S.H., Rothschild, R.E., and Serlemitsos, P.J. 1976, Ap. J., 209, L57.
- Takakura, T., Ohki, K., Shibuya, N., Fujii, M., Matsuoka, M., Miyamoto, S., Nishimura, J., Oda, M., Ogawara, Y., and Ota, S. 1971, Solar Phys., 16, 454.
- van Beek, H.F. 1974, Ph. D. Thesis (Utrecht).
- van Beek, H.F. 1975, Space Science Instrumentation, 2, 197.
- Vorpahl, J.A., Gibson, E.G., Landecker, P.B., McKenzie, D.L., and Underwood, J.H. 1975, Solar Phys., 45, 199.
- Vorpahl, J. 1972, Solar Phys., 26, 397.
- Widing, K.G., and Cheng, C.C. 1974, Ap. J. (Letters), 194, L11.
- Wild, J. P., and Smerd, S.F. 1972, Ann. Revs. Astron. Astrophys., 19, 159.
- Wolff, R.S., Helava, H., Kifune, T., and Weisskopf, M. C. 1974, Ap. J. (Letters), 193, L53.
- Zirin, H., and Tanaka, K. 1973, Solar Phys., 32, 173.

SECTION III

CONCEPTUAL STUDIES FOR SCIENTIFIC TRADEOFFS AMONG HARD X-RAY COLLIMATION AND DETECTOR DESIGNS

CONCEPTUAL STUDIES FOR SCIENTIFIC TRADE-OFFS
AMONG HARD X-RAY COLLIMATION AND DETECTOR DESIGNS

by

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June 1977

FINAL

This report will become Chapter III of the Phase A
report of the Hard X-Ray Imaging Facility Definition Team

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I. INTRODUCTION

A. Report Background

The University of California, San Diego (UCSD) is under contract to Goddard Space Flight Center (GSFC) to operate a "Facility Definition Team" (FDT) whose purpose is to define the scientific objectives, instrumental concepts and specifications, implementation and operation of an instrument to be placed on the Space Shuttle. The purposes of the instrument are to obtain hard X-ray images of the sun during the evolution of solar flares in order to understand non-thermal particle behavior on the sun; and to study cosmic X-ray source structures.

Since hard X-ray photons ($> \sim 10$ keV) cannot be reflected or refracted, the basic image-forming technique necessarily involves collimation of the incident X-ray flux. At the early meetings of the FDT, it was recognized that a number of collimator configurations were possible to obtain the scientific objectives of the facility. Each configuration, however, involved a different compromise in sensitivity, time and energy resolutions, angular resolution, image reconstruction, and technical feasibility. Accordingly, the team recommended that a detailed study of the scientific trade-offs between various types of hard X-ray collimators and associated detectors be made.

This report contains the results of the study as conducted at Caltech under NASA Contract NAS5-22375 Supplemental Agreement No. 1 through UCSD P.O. No. 6B-01363-0.

B. Organization of Report

In Section II of this report the parameters of the solar X-ray flux are reviewed in order to establish the regions of sensitivity, angular resolution, field of view, time resolution, etc., that would be appropriate for a shuttle facility. In Section III some basic quantitative relations are developed

for collimators, detectors, etc. which can be applied to most of the proposed collimation schemes. In Section IV each of the collimation schemes is discussed in detail, with appropriate numerical parameters. At this point some additional schemes, which might be considered for this application are introduced. Section V compares the sensitivity, angular response, etc., of all the configurations in a trade-off matrix, with discussion as needed. Section VI presents a summary of the trade-off considerations. An appendix compares output of three of the imaging systems when viewing a plausible source of solar hard X-rays.

II. PARAMETERS OF SOLAR X-RAY FLUX

A. Introduction

The scientific importance of solar hard X-ray imaging as an observational technique with which to study solar flares has been established in the interim report of the FDT. The purpose of this section is to review the known spectral, spatial and temporal characteristics of solar hard X-ray emission in order to form a basis for evaluating collimator schemes in subsequent chapters. Svestka (1976) provides a good review of the relevant observations.

For these purposes we can consider the X-ray emission to consist of three components. First, the non-thermal component which dominates X-ray bursts above 20 kev; second the thermal component which dominates bursts below 10 kev and is generally parameterized by a temperature and emission measure; and third, an "extended" component which is the X-ray analog to Type II and Type IV bursts observed at radio wavelengths. This component would originate higher in corona than the thermal or non-thermal burst sources and would be much larger in spatial extent.

B. Spectra of Burst Sources

Flare associated burst X-ray sources consist of a thermal and a non-thermal component.

The spectrum of the non-thermal component is usually fit by a power law so that the differential spectrum may be given by:

$$N(E) = F_{20} (E/20)^{-\gamma}$$

where $N(E)$ = Photon flux at 1 AU (photons / cm² sec kev)

E = photon energy (kev)

γ is usually in the range, $2.5 < \gamma < 6$ with a median value of 4 having been observed in a large flare sample (Datlowe et. al., 1974a). F_{20} , the instantaneous flux at 20 kev, varies during

a flare, of course, but a given flare may be characterized by the maximum value of F_{20} , A_{20} .

Statistics on flares accumulated by OSO-7 showed values in the range $0.1 < A_{20} < 30$ (photon $(\text{cm}^2 \text{ sec keV})^{-1}$), with an integral frequency distribution,

$$P(A_{20}) \sim A_{20}^{-0.8}$$

where $P(A_{20})$ is the expected number of bursts in any one 24 hour period with a flux at 20 keV of A_{20} or higher.

Such a differential spectrum generally holds from about 20 keV to about 100 keV, with some evidence of steepening above 60 - 80 keV which may indicate an additional non-thermal component or imply collisional relaxation.

The thermal continuum above ~ 5 keV can be parameterized by a temperature, T , and emission measure, $n_e^2 V$, with a differential spectrum given by Culhane and Acton, 1970.

Again, OSO-8 observations (Datlowe, et. al., 1974b) observed typical ratios in the range $1 \times 10^7 < T < 2 \times 10^7$ K and a peak emission measure $10^{47} < n_e^2 V < 10^{49} \text{ cm}^{-3}$, with larger values also observed on larger flares than the sample contained. In addition to the thermal continuum, above 5 keV there is also a complex series of Fe lines at 6 keV which no doubt contains a rich source of flare data. Since it does not significantly add to the total continuous photon flux as described above, it will not be considered further here.

The discussion above shows that both the thermal and non-thermal X-ray flux can vary widely from flare to flare. The relatively short duration of shuttle sortie missions makes it essential that the experiment be capable of effectively imaging the size of flare that would be expected to occur many times during such a mission. More specifically then, what are the spectral parameters describing a flare which might be expected to be observed about once a day?

Assuming 40% solar coverage (i.e., about 10 hours of solar viewing per day) a value of $A_{20} = 0.3$ photons $(\text{cm}^2 \text{ sec keV})^{-1}$ is expected while $Y = 4$ is also appropriate. The typical thermal emission from such a subflare would have $T = 1.5 \times 10^7$ K and $n_e^2 V = 3 \times 10^{48} \text{ cm}^{-3}$. The differential spectrum for such a "once-a-day" flare is shown in Figure II - 1.

From Figure II - 1, an integral flux for the "once-a-day" flare can be calculated and is shown in Figure II - 2. Note that during any 7 day mission there is a significant probability of observing at least one flare with an order of magnitude larger non-thermal flux and that flare to flare variation in T and $n_e^2 V$ could easily enhance the thermal flux by orders of magnitude as well.

These considerations indicate three significant points which will play an important role in subsequent collimator evaluation.

1. There is a large flare-to-flare variation in intensity at any one energy (eg. 10^{-1} to 10^3 ph/ $(\text{cm}^2 \text{ s})$ at 20 keV).
2. The spectrum is very steep, covering many orders of magnitude in a given flare.
3. The integral flux above 20 keV for the once-a-day flare is about 2 photons / $(\text{cm}^2 \text{ sec})$.

The first two points illustrate the severity of the dynamic range problem which must be addressed by system design of the window - collimator - detector combination. As we shall see below, the various collimator schemes differ significantly in their impact on the dynamic range problem.

The third point shows that a successful collimator approach must be capable of imaging at flux levels of ~ 2 photons $(\text{cm}^2 \text{ sec})$ if imaging of the non-thermal burst component is to be achieved. It is important to recognize the uncertainty inherent in such flux estimates because of the fluctuations in flare occurrence rates due to the solar cycle and active region histories.

C. Spatial and Temporal Characteristics of Burst Sources

The differences in the temporal behavior of thermal and non-thermal burst components is well established. The non-thermal or impulsive component typically has rise and decay times in the range 2-5 seconds and 3 to 10 seconds respectively. The FWHM of bursts varies from less than 10 seconds to $\sim 10^3$ seconds with 41 seconds as the median of one large data sample (Datlowe, et. al., 1974a). Fine structure within the burst as short as 1 to 2 seconds and below have also been observed (Frost, 1969; Van Beek, et. al., 1974). It is important to note that these observations are full disk averages so that variations with any one image "pixel" could well occur on a still shorter time scale.

The thermal component of bursts typically show a rise time of 10 to 300 seconds and decay times of 10^2 to 10^3 seconds or longer (Datlowe, et. al., 1974b) so that the driver for instrument time resolution clearly is the non-thermal component which suggests that a time resolution of 1 second or less is desirable.

The expected spatial character of thermal and non-thermal burst sources will prove an important determinant of the relative suitability of the different collimation schemes.

Skylab observations have directly shown the wide variations among soft X-ray burst source configurations (Kahler, et. al., 1975; Vorpahl, et. al., 1975). Size scales range from 5" to about 2' and consist of both diffuse, loop-like structure and X-ray knots (possibly unresolved) which produce a substantial amount of the total flux.

Although the non-thermal hard X-ray component spatial distribution has yet to be directly observed (except for a measurement by Takakura et. al., 1971, which placed an upper limit of one arc minute on its size), some idea of the size scale can be inferred from optical and radio data. Identifying the hard X-ray sources with H α kernels of emission suggest diameter of about 4 to 8 arc seconds (Vorpahl, 1972). White

light observations suggest that the emission could occur in distinct patches with size scales of 2-4 arc sec and larger (McIntosh and Donnelly, 1972; Rust and Hegwer, 1975). Interferometric measurements of impulsive microwave bursts imply substantial emission from structures as small as 2" (Kundu, et.al., 1975).

Thus the non-thermal hard X-ray images might be expected to show multiple bright features as small as 2".

D. Extended Sources

Characteristics of hard X-ray emission originating in the corona are more uncertain than those of the burst sources discussed above. Hudson (1975) has estimated the X-ray intensities which might be associated with storage regions and Type II, III, and IV bursts. Although the uncertainty in the expected fluxes is large, there is overlap with the range of flux to be expected for burst sources. Time scales range from ~ 1 second for the Type III analog to $\sim 10^3$ seconds and higher for the other cases. Thus the time resolution and intensity estimates should probably not be a driver for the sensitivity and time resolution of the experiment. Radio data suggests that the size scales can range from $< 2'$ for Type III associated sources to $10' - 15'$ for the Type IV cases. Thus a 2 arc minute field of view or period which would be adequate for burst sources would not be satisfactory. A full sun field of view and resolution $\sim 1'$ would be more appropriate in this case, at least for the initial "discovery" observations of such sources.

SECTION III

PROPERTIES OF MULTIGRID COLLIMATOR/DETECTOR SYSTEMS

A. Theoretical Response of Multigrid Collimators

Two types of collimators which have been extensively used in the past are Soller collimators and multiwire or multigrid systems. The Soller collimator consists of a bundle of parallel "tubes", generally of rectangular cross section whose response is simply related to the ratio of its cross section to its length. Such collimators feature excellent transmission (approaching 100%) but are not practical for angular resolutions better than a few arc minutes.

Multigrid collimators have been discussed elsewhere (Bradt et. al., 1968; Blake et. al., 1976a) and their principles will be briefly reviewed here. Such collimators consist of identical grids, each grid consisting of a large number of parallel wires of diameter, d_1 , with centers separated by a distance, $(d_1 + d_2)$. An equivalent response would be obtained by photoetching tungsten sheets to yield linear "walls" of width, d_1 , and linear holes of width, d_2 .

The angular responses of collimators for which $d_1 = d_2 = d$ and $n = 2, 3$ and 4 are illustrated in Figure III - 1a. It is important to note that the angular response can be characterized by three parameters; the FWHM resolution, R ; the period, P ; and the envelope FWHM, E . The collimator length, L , is defined as the separation of the top and bottom grid. The introduction of intermediate grids at $L/2$ and $L/4$ suppresses the "sidelobes". The resolution, R , is determined by L and the size of the apertures such that $R = \tan^{-1}(d/L) \approx d/L$. The period, P , is related to the resolution through the number of grids, n , by $P = R \cdot 2^{n-1}$. The envelope, E , determined by L and the overall collimator width, D , is $E = \tan^{-1}D/L \approx D/L$. For example, if $R = 4$ arc sec, $L = 3$ meters, the apertures in

the tungsten grid would have a width, $d = 58.2$ microns. A period of 32" would require 4 grids and if the collimator had a total width of $D = 4$ cm (implying $\frac{4 \text{ cm}}{(58.2 + 58.2 \text{ microns})} \approx 344$ apertures) the envelope FWHM, $E \approx 40'$.

Linear apertures such as described above yield a high resolution collimating structure in one direction. The angular response in the other direction simply has a triangular profile whose FWHM, E' is given by $E' \approx D'/L$, where D' is the length of the linear apertures. Note that $E' = E$ only for a square collimator in which $D = D'$.

Referring to figure III-1a, it should be noted that if $P \geq E$, then there is only a single response peak. Such a collimator is "non-periodic". In this report, the term "non-periodic" will also apply to any collimator in which $P > 32'$ since at most only one response peak would be viewing the sun at any one time.

The generalization to 2 dimensions of the one dimensional collimator described above is straightforward with the addition of an orthogonal set of linear apertures. These may be mechanically decoupled, bonded to the first set or formed by the etching of a pattern of rectangular holes in a single tungsten sheet. Note that the angular response in each direction need not necessarily be made the same.

As described above, the transmission of such a collimating structure (i.e., the ratio of hole area to the total area) when $d_1 = d_2$ is 50% and 25% for one and two dimensional collimators respectively. Higher transmissions can be achieved by making $d_1 < d_2$, viz., by using thinner walls (McGrath and Harwit, 1969). To get the same angular response, however, it is necessary to increase the number of grids. (The limit of $d_1/d_2 \rightarrow 0$, $n \rightarrow \infty$ corresponds to the Soller-type collimator.)

In practice, transmissions may be lower than the nominal 25% and 50% outlined above due to the necessity of allowing an error budget for grid misalignment. In the ideal collimator

analyzed above, any displacement of an intermediate grid will change the transmission profile. To eliminate the calibration complexities of such an occurrence the apertures of the top and bottom grids are each reduced by a small amount, $2t$. Then any intermediate grid displacement of $\pm t$ does not affect the transmission. The overall transmission of such a collimator is reduced, however, for if the intermediate grids have $d_1 = d_2 = w$, and if the aperture of the outer grids is $d_1 = d$ (determined by the resolution requirement), then the error budget $t = (w - d) / 2$, and the one dimensional transmission,

$$\begin{aligned} T_1 &= d/2w \\ &= \frac{1}{2} \frac{d}{(d + 2t)} \end{aligned}$$

The two dimensional transmission,

$$T_2 = T_1^2 = \frac{1}{4} \frac{d^2}{(d + 2t)^2}$$

In this report an error budget of $t = 9.7$ microns is adopted (similar to the value quoted in the Utrecht SMM experiment proposal for a multigrid collimator). For a 4" collimator ($d = 58.2 \mu\text{m}$) this leads to transmission of 0.375 and 0.141 for one and two dimensional collimators, respectively.

The error budget, t , encompasses not only misalignment problems, but also some thermal effects, layout and fabrication tolerances, etc.

It should be recognized that for a given resolution, an important tradeoff area exists among transmission, period, number of grids and the error budget. Since this tradeoff does not significantly affect the relative sensitivity of the various collimation schemes, it will not be considered further here.

It is necessary to point out however, that in order to apply this technique to periodic collimators, a judicious

repositioning of the collimator inner grids is required. An example of a 6 grid collimator with 4" resolution, 128" period and a 9.7 micron error budget is shown in Figure III-1c.

An alternative approach to multigrid collimator design is provided by the use of random grid patterns (e.g., Blake et. al., 1976b). In such a system a set of identical grids are fabricated with a pattern of randomly placed apertures whose "diameter" is determined by the desired resolution. If sufficient grids are used, excellent side lobe suppression can be obtained with good transmission by a central non-periodic response peak. Although such systems could well play a role in systems requiring a multigrid, non-periodic collimator, such a possibility does not materially affect the tradeoffs among collimator systems and so they will not be considered further here. (This type of multigrid collimator should not be confused with the Dicke scatter-hole camera.)

B. Subcollimator Concept

The multigrid collimator described above has an angular response which (except for the weighting of sidelobes) is uniform over the entire collimator dimension, D. Many collimation systems require a large number of collimators, each with a different angular response, though perhaps with a common choice of grid locations. Rather than fabricating, aligning and co-aligning a large number of such collimators, the use of subcollimators provides a convenient technique by which this can be accomplished. To use such a technique each tungsten grid is divided into a number of regions, each separated by a few millimeters, and within each section (called a subcollimator) an appropriate pattern of apertures is etched. (See Figure III-2). A number of properties of such a set of subcollimators should be noted.

1. The angular response of each subcollimator need not necessarily be related to the response of other

subcollimators.

2. If the design and fabrication of the grids is done correctly, correct alignment of the grid implies alignment of all the subcollimators within the grid.
3. The coalignment of subcollimators within a grid is determined by the design and fabrication and is relatively immune to subsequent misalignment.
4. Alignment implications of rotational errors and thermal expansion are less serious.
5. Detectors which view each subcollimator must be carefully intercalibrated in terms of energy if low contrast features are to be faithfully reproduced, particularly in the case of a steep spectrum of incident photons.
6. Separating each subcollimator from the next by a few millimeters results in some inefficiency in the use of grid area, but has three advantages:
 - a. Provides additional mechanical strength for the grid.
 - b. Permits a detector of moderate resolution to provide clean identification of which subcollimator a detector photon passed through.
 - c. Discourages the transmission of photons which enter one subcollimator in the top grid with the aim to pass through an adjacent subcollimator in a subsequent grid. (This possibility can be eliminated entirely by the use of very coarse slats between subcollimators.)

One particularly useful special case of the subcollimator concept involves (in one dimension) displacing the central response peak in each subsequent subcollimator from that of the previous subcollimator by an angle equal to its FWHM resolution for N subcollimators where $N = (\text{Period}/\text{Resolution})$. The result, as suggested by Figure III-2, is that (subject to

envelope restrictions) each source point is viewed by at least one subcollimator, with the additional property that all such sources are detected with the same total effective area. Such a "periodic phased array" of subcollimators provides high resolution observations over a wide field of view (envelope) with a relatively small number of subcollimators and consequently a relatively high efficiency. The two main drawbacks of the periodicity are that (1) additional information (from non-hard X-ray data or from an additional set of coarse collimators) is necessary to resolve the ambiguity of which response peak in a subcollimator viewed the source (i.e., the source location is uncertain to an integral multiple of the period); (2) image confusion results if the source extent exceeds the period.

The properties of a phased array of fan beam subcollimators described above are retained in the generalization to two dimensions. In this case $N = (\text{period}/\text{resolution})^2$ elements are required, but the uniformity of field property still holds if square apertures are used.

C. Collimator Frames

Three limitations are relevant in determining how the 1m x 1m frontal area of the collimator is configured.

1. An upper limit (20-25 cm) to the dimensions of a tungsten grid which can be fabricated and supported.
2. The need to allocate a substantial fraction of this area (~ 40%) to grid support, metering structures, etc.
3. An upper limit to the size of detectors (or detector arrays).

Thus a typical configuration of the 1m x 1m frontal area might involve 16 "frames", each of which supported one tungsten grid for a total area of $\sim 6000 \text{ cm}^2$. Each grid (19.4 x 19.4 cm) could contain an arbitrary number of subcollimators, subject to the necessity of a "wall" between each whose role is dis-

cussed above. (See Figure III-3) Frame to frame coalignment can be verified by an in-flight calibration on a cosmic point X-ray source while subcollimator to subcollimator coalignment within a given frame should be relatively stable as indicated above.

D. High and Low Energy Limits to System Response

This subsection considers those factors which are relevant in determining the high and low energy limits to system response. These considerations are applicable to all the collimation schemes considered, with scaling parameters discussed in subsequent sections.

It would be desirable to have the low energy limit below 5 kev in order to significantly overlap with the focussing soft X-ray detectors, and to increase the system sensitivity to cosmic X-ray sources and lower temperature solar sources. Two practical considerations must be faced, however, in establishing a lower limit.

1. In order that the energy spectrum of non-thermal X-rays be correctly determined, it is essential that the count rate be limited to prevent pile-up (e.g., Kane and Hudson, 1970). Thus a window must be provided to cut off the incident spectrum at a sufficiently high energy to limit the count rate. Figure II-1 indicated the effect of one such window choice which cuts off the spectrum at ~ 4 kev.
2. Diffraction is a potential concern at low energies for collimators with the size scales considered here (Schmidke, 1970; Blake, et. al., 1976a). A criterion for establishing the wavelength below which diffraction should be considered is

$$\lambda = \frac{d^2}{2L}$$

For example if $d = 58.4$ microns, $L = 3$ meters (4" resolution) diffraction may be of concern below 2 kev. Note that this energy scales inversely as the square of the angular resolution for a collimator of fixed length.

At high energies, it would be desirable to extend the sensitivity up to ~ 100 kev in order to investigate the implications of the break in the non-thermal power law spectrum.

A high energy limit is imposed, however, by four factors.

1. The steep spectrum of incident photons places significant statistical limits on high energy imaging.
2. Background spectra are expected to be much harder than source spectra and so can seriously affect the high energy response. (See Figure II-1)
3. Detector efficiency becomes a concern at high energies particularly if Xenon proportional counters are used.
4. Grid transparency can become a concern since well-defined apertures cannot be etched in a tungsten sheet significantly thicker than the size of the aperture. Thus with an aperture size fixed by the angular resolution, thicker tungsten grids require stacking of several identical grids (Blake, et. al., 1976b). Numerically, a 58 micron tungsten grid provides one absorption length at 40 or 70 kev but because the K edge of tungsten is 69.5 kev, about 4 such grids would need to be stacked in order to provide a $1/e$ attenuation at 69 kev. Those systems which are immune to this problem will be indicated in Section V.

The first two considerations will be found to vary significantly in their impact among the collimation systems and so in this respect, the choice of collimation scheme will materially affect the practical upper limit to the energy

range. The significance of the third consideration also is dependent on the choice of collimator schemes in that some approaches require spatially resolving detectors with resolution characteristics that are possible only with proportional counters. The potential efficiency advantage of solid state or scintillation detectors could not be applied in such cases.

The interplay of grid transparency, diffraction and error budget considerations are illustrated in Figure III-4. It shows that careful consideration of the effects needs to be undertaken if angular resolution as low as 1 or 2 arc seconds were to be contemplated.

E. Dithering

The use of a phased array of subcollimators to view an extended field of view as described in Section III-B above would appear to have limited potential for resolving source details at a level smaller than the resolution FWHM. Recalling the overlapping character of the response of adjacent subcollimators (see Figure III-2) it is clear that the location of a single point source could be determined to better than the FWHM resolutions from the ratio of the counts in the corresponding two illuminated detector elements. However, information as to whether the source had finite extent or was a closely spaced double source, etc, would be seriously compromised.

This potential disadvantage could be overcome if the collimator executed a relatively slow, small amplitude dithering motion (e.g., 10" amplitude, 2 second period). By doing this, a given subcollimator could view the source with its entire resolution profile which can subsequently be deconvolved. A simulated example showing the potential advantages of such a procedure is illustrated in Figure III-5.

IV. DESCRIPTION OF REFERENCE SYSTEMS

A. Introduction

In this chapter fourteen different collimation schemes will be described. Some of these schemes have been used successfully in balloon, rocket and satellite observations over the last decade. Others have been seriously proposed or are under development for future missions. Some of these schemes suggested themselves during the course of this study and have not (to the author's knowledge) been discussed elsewhere. The list of fourteen schemes discussed below should by no means be considered exhaustive. In particular many combinations and adaptations of the schemes listed below are feasible. A few are suggested at the end of this chapter.

B. Baseline Parameters

A quantitative intercomparison of the fourteen schemes to be discussed requires that each be baselined to a particular set of overall dimensions, spatial resolution, field of view, energy range, etc. Rather than optimize each scheme to illustrate its maximum potential, a set of baseline parameters was chosen that are appropriate for observing solar bursts and extended sources and yet practical for the majority of the collimation schemes. The reference systems described below consist of the fourteen collimator schemes with design parameters chosen to meet the baselined values of spatial resolutions, etc. Where appropriate, the effects of changing the baselined values will be indicated in Chapter V.

The baseline volume associated with each system is 1 m by 1 m by 3 m long. Such dimensions would be appropriate for a standard SIPS pointing system whose sub-arc-second pointing accuracy and stability are also assumed in each case. The baselined SIPS scanning rates are also implicitly assumed.

A basic angular resolution of 4 arc seconds FWHM is

adopted. Such an angular resolution is a compromise. A value of 1 or 2" would be desirable to explicitly resolve solar hard X-ray sources whose dimensions have been inferred from soft X-ray, radio and optical data. The discussion in Section III (see Figure III - 4), however, indicated that a resolution of 1 or 2" might be difficult to achieve because of alignment tolerances, aperture dimensions and diffraction effects. A resolution of 4" eases these problems and yet still permits deconvolution of a well-defined resolution profile so as to frequently "resolve" 1 or 2" sources. The effects of changing this basic resolution is discussed in Chapter V.

A whole sun field of view is assumed for those systems for which it is practical. In most cases a maximum source extent is assumed to be about 2 arc minutes so that high resolution elements of periodic systems are assigned a period of 128 arc seconds. Such systems would be capable of unambiguously imaging a source anywhere on the sun provided its maximum linear dimension did not exceed about 2 arc minutes. Section II indicated that this would be adequate for virtually all burst sources.

Systems with nonperiodic collimators either have full sun field of view or about a 2 arc minute field of view. In the latter case pretargeting on an active region is of course necessary and the possibility of missing part or all of some flares is present. The consequences of changing the field of view are indicated in Section V.

Periodic systems are also provided with sets of $\sim 1'$ or $\sim 2'$ coarse collimators which can be used to unambiguously locate the sources observed by their high resolution periodic elements. In addition, 1 arc minute is an appropriate choice for viewing extended sources.

Finally, an energy range of 5 to 100 keV is baselined. The relative practicability of these limits is determined (for a given window/detector choice) by parameter defined

and evaluated in Section V for each reference scheme.

C. Reference Systems

1. Pencil Beam

Conceptually, perhaps the simplest method of image formation is to have the entire collimator view the same point on the sun. Images would be built up by mechanically rastering the 4" x 4" collimator as shown in Figure IV - 1. Such a system would be analogous to single dish mapping of extended sources in radio astronomy.

For the purpose of calculating sensitivities, a 128" x 128" raster pattern is assumed. An absolute minimum of 32 seconds would be required to complete a 32 line - 2' raster.* The actual size of the pattern could easily be changed on command according to the burst dimension anticipated for a given solar active region.

2. Multielement Pencil Beam

The rapid raster motion required by the pencil beam system outlined above can be eased somewhat by the use of a multielement pencil beam. In such a system, the total collimator area is divided into 32 subcollimators, each of which has a 4" x 4" resolution. The centers of the fields of view are arranged in a row as shown in Figure IV - 1. A simpler one dimensional scanning motion (period of ~4 seconds minimum*) perpendicular to this row enables any source within the 128" x 128" field of view to be periodically viewed.

3. Multielement Collimator Array (MECA)

The scanning motions required by the previous two systems is eliminated completely by the approach taken here. The total collimator area is again divided into

* Assuming SIPS baselined scanning capabilities.

subcollimators, each with 4" x 4" resolution, but in this case these are 1024 subcollimators whose axes are arranged in a rectangular grid covering the 128" x 128" field of view. (See Figure IV - 1) No mechanical motion is required.

This system is similar to that proposed by the Utrecht group for the X-ray imaging experiment on SMM.

4. Imaging Collimator

The imaging collimator (Bradt et. al., 1968) provides a collimation technique for directly imaging the source at the detector. The geometry which can accomplish this is suggested in Figure IV - 2. Note that each point on the detector sees a 4" x 4" area of the source, with contiguous detector locations seeing contiguous areas. The detector spatial response folded into the 4" x 4" collimator response determines the overall angular response of the system. The system can be configured to have a 128" x 128" field of view by an appropriate choice of design parameters. (With such a choice a 1 cm. displacement at the detector corresponds to a shift in the central response peak by 1-2/3 arc sec). Despite its apparent differences, the effective response of such a system is very similar to the multi-element collimator array described previously.

5. Periodic Multielement Collimator Array

The previous systems have had the disadvantage of a 128" x 128" field of view. Such systems would require pretargeting at an active region and could easily miss flares occurring at other active regions.

This limitation can be removed, for example, in the case of the Multielement Collimator Array by making each of the subcollimators periodic with a period of 128". In this way every point on the sun is within a

FWHM of one of the subcollimators and the array as a whole can be considered to have full sun coverage.

The high resolution subcollimators are supplemented by an additional 256 subcollimators, each of which has a 128" x 128" resolution. These coarse elements remove the ambiguity associated with the periodic fine elements as well as provide some extended source imaging capability.

6. Foveal System

The systems described above will be seen in the following chapter to have the disadvantage of relatively low sensitivity. The basic reason for this is that the available total collimator area (or collimator area-time product for scanning systems) has had to be divided by $\sim 10^3$ in order to have the desired field of view and resolution combination. A given source on the sun effectively illuminates only a few of these subcollimators and so the effective area is relatively small. For the spatial characteristics expected for hard X-ray sources, this is inefficient since almost all of the emission is expected to be in highly compact knots, loops, etc. Thus the majority of subcollimators at any one time are looking at black sun. The foveal system outlined below is an attempt to make more efficient use of the available collimator area by looking primarily at those locations which are emitting X-rays. In this case the collimator is divided into 100 subcollimators of which 64 have 4" x 4" resolution and form a 32" x 32" central field of view. In addition there are four sets of 9 subcollimators with resolution 32" x 32", 1.6' x 1.6', 4.8' x 4.8' and 14.4' x 14.4' respectively whose fields of view are arranged as shown in Figure IV - 1 to form a hierarchy with the highest resolution elements grouped in the center and the combination viewing the full sun.

A burst occurring anywhere on the sun would be

detected by one of the elements. A microprocessor control system would then issue commands to the pointing system so as to direct the high resolution elements to the location of the burst. This could be done within ~1 to 2 seconds. Should the burst be larger than the 32" x 32" high resolution field of view, this would be sensed by the 32" resolution elements and the pointing system directed to 'time share' the high resolution elements among the different regions of interest.

This system would always be alert to the full sun although only the center of its field of view would be imaged with the highest resolution. It is analogous to the human eye which responds by turning to look at objects of interest which are first sensed by peripheral vision.

7. Fan Beam Modulating Collimator

The fan beam modulation collimator in its simplest form consists of a one dimensional collimator with high angular resolution in one dimension which is scanned back and forth across the source in the direction of high resolution. As parts of the source are successively transmitted and blocked by the collimator, the resulting detector rate plot represents a one dimensional projection of the two dimensional source distribution. If fan beams with different orientations are used simultaneously a set of such one dimensional projections are obtained.

An additional data forming stage is necessary to convert a set of one dimensional scans to a two dimensional image.

In the reference fan beam system, six fan beams are provided with 4" FWHM resolution and 128" period. Their relative orientations are 15, 45, 75, 105, 135, and 175 degrees with respect to the scanning axis. In addition there are 4 fan beams with 64" resolution and 34.1' period with orientation of $22\frac{1}{2}^\circ$, $67\frac{1}{2}^\circ$, $112\frac{1}{2}^\circ$, and $157\frac{1}{2}^\circ$ relative to the scanning axis. These low resolution

fan beams serve the dual purpose of removing potential source location ambiguities associated with the high resolution elements and imaging extended coronal sources.

The entire collimator structure is scanned through 34' with a 4 second period so that the average time resolution is 2 seconds for the low resolution elements and 0.1 seconds for the high resolution periodic elements.

8. Multiple Fan Beams

This system differs from the Fan Beam Modulation Collimator just described primarily in the manner in which the one dimensional projections of the two dimensional sources are measured. Instead of a single fan beam mechanically scanned across the source, the multiple fan beam system uses a set of fan beams, each of which views an adjacent strip of the sky (Figure IV - 3). Dithering permits full advantage to be taken of the triangular beam profile. One dimensional projections of the source are converted to two dimensional images as described above.

In the reference system six sets of high resolution fan beams are provided. Each set has 32 - 4" FWHM resolution, 128" period fan beams with a given orientation and adjacent fields of view. In addition four sets of low resolution fan beams are provided with 64" resolution and a 34.1' period. Apart from a small dither, no mechanical scanning is necessary.

9. Rotating Modulation Collimator

The rotating modulation collimator (Schnopper, et.al., 1968, Willmore, 1970) has been successfully used on a number of rocket and satellite payloads to provide a wide field of view collimation system which is capable of accurately locating point sources in two dimensions. The collimator, which has a fan beam angular

response when stationary, is rotated about its axis of symmetry so that a point source located off-axis is alternately shadowed and exposed. The resulting detector count rate plot is similar to that shown in Figure IV - 4. As the figure suggests, the number of count rate maxima during a half-resolution of the collimator is dependent on the angular separation of the source and collimator axis while the phase of the maxima depends on the azimuthal position of the source. Such count rate plots can be used to locate a point source in two dimensions, although with 2 provisos. First there is a two-fold ambiguity in the deduced source position with the two apparent positions symmetrically located with respect to the collimator axis. Second, the accuracy with which the radial and azimuthal locations are determined are in general not the same. The use of rotating modulation collimators in identical pairs with non parallel axes of rotation serves not only to minimize these effects, but also to greatly reduce gyroscopic effects associated with their rotation.

For the reference system, four rotating modulation collimators are provided. Two of these are high resolution systems with 4" resolution and 128" period for imaging burst sources and two are low resolution (64" resolution and 34.1' period) for viewing extended sources. Note that the low resolution fan beams are not necessary for removing source location ambiguities. The axes in each case are slightly off the solar disk with one high/low resolution pair being displaced about 1° from the other. A rotation rate of 60 RPM would give a basic time resolution of 0.5 seconds. With 4 collimators, gyroscopic effects can be completely eliminated.

10. Scatter Hole Camera

The principle of the scatter hole camera (Dicke, 1968) is illustrated in Figure IV - 5. The camera consists of a single opaque grid containing a large number of randomly located apertures. At an appropriate distance, a spatially revolving detector is required. A point source illuminates the detector in a pattern corresponding to the grid, with the pattern displacement determined by the source location.

For the reference system to have 4' resolution the aperture diameter and detector spatial resolution should be 60 microns.

11. Scatter Hole and Mask System

The scatter hole camera described above will be found to have about 2 orders of magnitude more sensitivity than any of the previously described reference systems. It will be found, also, to have the critical disadvantage of requiring a detector system with 60 micron resolution over its 1 m x 1 m area. Since such a detector is not available at present, the scatter hole and mask system now described provides a way to trade sensitivity for a relaxed detector spatial resolution requirement. The scatter hole and mask system is similar to the scatter hole camera except that an opaque mask with regularly spaced apertures is located immediately in front of the detector. The apertures have a 58 micron diameter and are located in a rectangular grid with separations of $(32 \times 58.2 \text{ microns} =) 1862 \text{ microns}$. This permits the use of a detector with spatial resolution $\sim 1 \text{ mm FWHM}$ to associate each event with the correct aperture in most cases, thereby providing a detector - mask system with effective spatial resolution of 60 microns. Although a 1 mm FWHM detector will occasionally misidentify an aperture, the effect of this is to generate sidelobes displaced by $128''$ from the central peak of the systems point response function.

12. Scatter Strip and Mask System

Structurally this system is similar to the scatter hole and mask scheme described above. In this case, the top grid has a set of parallel, 58 micron linear apertures, randomly spaced. The mask at the detector has a set of parallel, 58 micron linear apertures, evenly spaced every 1.862 mm. The detector requires a one dimensional spatial resolution of ~ 1 mm. This is therefore, a one dimensional version of the scatter hole and mask system. The deconvolved output from each subcollimator is a one dimensional projection of the source so that each subcollimator effectively has a fan beam response.

Output from all six subcollimators can then be combined as with more conventional fan beam systems to yield a two dimensional image.

13. Pin Hole Subsatellite

This system, which is pictured in Figure IV - 6 and is described more fully elsewhere (Hudson, 1976) features a simple subsatellite launched (and perhaps retrieved) by the shuttle. The subsatellite station keeps at an appropriate distance from the shuttle in a direct line between spacelab and the sun. The subsatellite is basically an opaque disk with a clear aperture which forms a large scale, direct, inverted image of the sun on a detector system mounted in the orbiter bay. (A conceptual equivalent might have a mask raised into position on the shuttle projecting a shadow image onto the detector located on a subsatellite.)

In this case a 3.3 cm diameter aperture in a 1.7 km distant subsatellite provides a 4" FWHM image with a 128" field of view at a detector system which needs only ~ 3.3 cm spatial resolution. Note that the aperture could be varied to give the highest possible resolution consistent with count rate statistics.

14. Remote Scatter Hole System

This system applies the potential sensitivity advantages of the scatter hole camera to the subsatellite concept. A scatter hole grid with 2 mm apertures located 100 meters from the detector (either on a subsatellite or a boom) would require a detector with 2 mm position sensitivity to provide full sun viewing with 4" resolution. Although the position of the remote grid needs to be known to $\sim \frac{1}{2}$ mm it need not be controlled to better than a few centimeters.

D. Variations of the Reference Systems

As was mentioned at the beginning of this chapter, the list of fourteen schemes outlined above can spawn a host of other possible collimator configurations.

For example, periodic versions of any of the first four systems are certainly possible. The imaging collimator concept could easily be adapted to the multiple fan beam or the multielement pencil beam scheme. The foveal system could effectively use low resolution fan beams to direct it to a location of interest instead of using the hierarchy of coarse pencil beams for this purpose. Additional periodic elements might be added to a foveal system to provide high resolution coverage before and during its 'response time'. A multiple beam version of the rotating modulation collimator is also feasible. One dimensional versions of any of the scatter hole systems are certainly possible. There is, no doubt, a continuum of such approaches.

Since full evaluation of such a continuum is not feasible, it is hoped that the tradeoffs discussed in Chapter V should serve as a guide to which variations and combinations might be potentially useful.

V. TRADEOFFS AMONG REFERENCE SYSTEMS

In this section the 14 reference systems described previously are compared under the six general headings of angular response, collimator characteristics, detector characteristics, sensitivity, time resolution and telemetry, and miscellaneous. These comparisons are displayed in matrix form in six corresponding tables with the entries explained and discussed in the text.

A. Angular Response

Table V-1 summarizes the characteristic angular responses of the fourteen reference systems. Where appropriate, the responses of different sets of subcollimators of a given system are tabulated separately.

The field of view of each system is shown in the second column. This refers to combined response of a set of subcollimators (when scanned, rastered or rotated) and does not necessarily refer to the response of a single subcollimator.

FS - Collimator views full sun with no ambiguity.

PFS - Collimator response is periodic over the full sun, with the period indicated in column 4. Note that there could be some image confusion associated with sources larger in extent than the period.

Although the resolution FWHM has been set at 4" for all the systems there are some differences among the systems as to their resolution profile which may be defined as the Bayesian probability distribution of the location of a point source detected in a single subcollimator. A well-defined resolution profile is important if source details smaller than the resolution FWHM are to be inferred.

T1 - For systems with resolution profile type "T1", the angular response (in 1 dimension) is determined by the equal apertures in the top and bottom grids and so the one-dimensional response has the triangular

TABLE V-1 ANGULAR RESPONSE *

System	Field of View	Resolution FWHM	Period	Resolution Profile Type	Number of Fan Beam Orientations	Image Coding	Deconvolution Required	Image Completeness	Limitation on Resolution Improvement
1. Pencil Beam	128x128"	4"	-	T2'	-	D	no	yes	GF,A,S,D
2. Multielement Pencil Beam	128x128"	4"	-	T2'	-	D	no	yes	GF,A,S,D
3. Multielement Collimator Array	128x128"	4"	-	T2'	-	D	no	yes	GF,A,S,D
4. Imaging Collimator	128x128"	4"	-	T2'	-	D	no	yes	GF,A,S,D
5. Periodic MECA	PFS FS	4" 128"	128" -	T2	-	D	no	yes	GF,A,S,D
6. Foveal System	32x32" 1.6x1.6' 4.8x4.8' 14.4x14.4' FS	4" 32" 1.6' 4.8" 14.4'	- - - -	T2	-	DK	no	yes	GF,A,D
7. Fan Beam Modulation Collimator	PFS FS	4" 64"	128" -	T1'	6 4	D-1P	yes, for 2D images	for "simple" sources only	GF,A,S,D
8. Multiple Fan Beams	PFS FS	4" 64"	128" -	T1	6 4	D-1P	yes, for 2D images	for "simple" sources only	GF,A,S,D
9. Rotating Modulation Collimator	PFS FS	4" 64"	128" -	X	2 2	R	yes	in principle	GF,A,S,D
10. Scatter-hole Camera	FS	4"	-	C	-	S	yes	yes	GF,DR,D
11. Scatter hole and Mask System	FS	4"	-	T2	-	S	yes	yes	GF,S,D
12. Scatter strip and Mask	FS	4"	-	T1	6	S-1P		for "simple" sources only	GF,S,D
13. Pin hole	128x128"	4"	-	C	-	D	yes	yes	S
14. Remote Scatter-hole	FS	4"	-	C	-	S	yes	yes	-

* See text for explanation of abbreviations.

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profile as indicated in Figure III - 1.

T2 - In two dimensions this response becomes $(1 - |x|/4)(1 - |y|/4)$, where x and y are the angular displacements relative to the subcollimator axis.

T1' - This profile is similar to T1 except that it is smoothed by the effective time resolution since the triangular profile is being mechanically scanned.

T2' - This profile is similar to T2 except that it is convolved with the spatial resolution of the detector or is smoothed by the mechanical scan.

X - The angular response of the rotating modulation collimator is unique in that it is non-uniform over the field of view and in addition is not symmetrical. Typically the source position can be much better defined in terms of its radial distance from the collimator axis than in its "azimuthal" location (Schnopper et. al., 1968).

C - For these systems, the profile is a straightforward convolution of the aperture shape and detector spatial response.

The next three columns indicate the related issues of image coding, completeness and deconvolution requirements.

D - The images from these collimators are directly coded, either in terms of a time sequence of counts or by association of counts with a particular subcollimator. Image formation in such cases is a straightforward procedure, given the aspect solution. No deconvolution is required. The images are complete in the sense that the source complexity cannot introduce any ambiguity into this process.

DW - Image formation with the foveal system is as direct

as described above, except that some weighting may be necessary depending on how the system "time shared" its high resolution elements over larger sources.

D-1P - With fan beam systems, formation of 1 dimensional projected image is direct and straightforward. Some interpretation can be done using the one-dimensional projections (source extent, time variability of source configuration, spectral changes, etc.) and in this sense the fan beams directly provide information analogous to the direct interpretation of the output of a radio interferometer (where fringe amplitudes can provide a measure of source size, for example). But just as earth rotation synthesis is used to convert radio interferometric data into two dimensional images, so an additional deconvolution step in data reduction is required to form images from the fan beam data.

The limited number of fan beams does not permit a "complete" image to be reconstructed in all cases. That is, if the source were spatially very complex, there would not be a unique solution to the deconvolution problem. (This is analogous to having incomplete u-v plane coverage in radio interferometry.) In practice, however, the expected high contrast nature of the hard X-ray source is well suited to deconvolution. Many techniques are available for doing this (Algebraic Reconstruction, Fourier Synthesis, Maximum Entropy, Bayesian Probability.) (e.g. Gaarder and Herman, 1972; Gordon et. al., 1976; Gilbert, 1972).

R - Figure IV - 4 illustrates the indirect manner in which rotating modulation collimators are encoded.

Fast algorithms have been developed and used successfully (for example, with the SAS-3 rotating modulation collimator) for the deconvolution of such data to yield point source locations. In principle, given sufficient statistics, a complete image can be reconstructed.

S - Figure IV - 5 shows the image encoding for the scatter-hole camera (Duke, 1968). The deconvolution of such data has been investigated by a number of workers (e.g. Brown, 1972; Blake et. al., 1974) with the result that digital techniques are available and have been demonstrated with sources of modest complexity. It has been shown that image completeness can be attained, even for extended, low contrast images.

S-1P - The scatter-strip and mask system would yield data encoded in a 1 dimension analogue to the scatter-hole camera data described above. Similar (and probably simpler and faster) techniques could be used to yield a complete 1-dimensional projection, at which point a second deconvolution stage, similar to that described above for fan beam systems, would be required to convert the 1-dimensional projections into a 2 dimensional image.

The final column of Table V-1 indicates some potential limitations that could apply if the angular resolution of each of the systems were to be significantly improved.

GF - Grid fabrication could become a problem since higher resolution would require smaller apertures. The total thickness of each grid could not be reduced if high energy responses were to be maintained. Only the subsatellite or tethered boom systems are immune from this problem.

- A - Maintaining grid alignment becomes a more severe problem for multigrid collimators as aperture sizes are decreased. The transmission/error budget/period/ grid count/ resolution tradeoff is relevant here.
- S - Sensitivity could not be maintained in any system except the scatter-hole devices unless the field of view were correspondingly reduced. (See Table V-4.)
- D - Diffraction is a potential limitation at low energies for all the self-contained collimator systems.
- DR - Detector spatial resolution is a severe limitation for the scatter-hole camera.

B. Collimator Characteristics

The collimator characteristics of each of the reference systems are listed in Table V-2. The resolution and period values are taken from the discussion in Section IV. The different grid types are indicated in the fourth column.

- 1D - One dimensional grids with regularly spaced, linear apertures.
- 2D - Two dimensional grids with regularly spaced rectangular apertures (can be fabricated by combined two orthogonal one-dimensional grids).
- S1 - One dimensional grids with randomly spaced, linear apertures.
- S2 - Two dimensional grids with randomly spaced apertures (square, circular, or hexagonal).
- M1 - One dimensional mask, largely opaque with regularly spaced linear apertures.
- M2 - Two dimensional mask, largely opaque with regularly spaced apertures (square, circular, or hexagonal).
- A - A single large aperture.

TABLE V-2 COLLIMATOR CHARACTERISTICS

	System	Angular Resolution FWHM	Period	Grid Type	Number of Grids	Number of "Frames"	Total Grid Count	Aperture Size	Critical Alignment Count
1.	Pencil Beam	4"	34.1'	2D	10	16	160	58 μ m	400
2.	Multielement Pencil Beam	4"	34.1'	2D	10	16	160	58 μ m	400
3.	Multielement Collimator Array	4"	34.1'	2D	10	16	160	58 μ m	400
4.	Imaging Collimator	4"	34.1'	2D	10	16	160	58 μ m	400
5.	Periodic MECA	4" 128"	128" 34.1'	2D 2D	6 5	12 4	92	58 μ m 1.9mm	156
6.	Foveal System	4" 32" 1.6' 4.8' 14.4'	34.1' 34.1' 51.2' 38.4' 43.2'	2D 2D 2D 2D 2D	10 7 6 5 4	12 1 1 1 1	142	58 μ m 0.47mm 1.4mm 4.2mm 12.6mm	300
7.	Fan Beam Modulation Collimator	4" 64"	128" 34.1'	1D 1D	6 6	12 4	96	58 μ m 0.93mm	108
8.	Multiple Fan Beams	4" 64"	128" 34.1'	1D 1D	6 6	12 4	96	58 μ m 0.93mm	108
9.	Rotating Modulation Collimator	4" 64"	128" 34.1'	1D 1D	6 6	8 8	96	58 μ m 0.93mm	72
10.	Scatter-hole Camera	4"	-	S2	1	16	16	58 μ m	0
11.	Scatter-hole and Mask System	4"	-	S2/M2	2	16	32	58 μ m	0
12.	Scatter-strip and Mask	4"	-	S1/M1	2	16	32	58 μ m	16
13.	Pin Hole	4"	34.1'	A	-	-	-	3.3cm	0
14.	Remote Scatter-hole	4"	-	S2	-	-	-	2mm	0

The number of grids required is indicated in the fifth column. For non-periodic multigrid collimators, this number, N , is determined by the relation, $2^{N-1} = \text{Period/Resolution}$, discussed in Section III. For periodic collimators, where the period is 32 times the resolution, 6 grids are required as illustrated by Figure III - 1. Note that although no grids are indicated for the pinhole or remote scatter-hole systems, relatively coarse aperture(s) would have to be provided. In addition, coarse collimation would undoubtedly be required at the detector to aid in background suppression.

As indicated in Section III, both the metering structure and grid fabrication would undoubtedly require the 1m x 1m frontal area of the collimator to be divided into a number of "frames" (eg.16) so that individual grids could have an area ~ 20 cm on a side. An appropriate allocation of such frames among the different angular resolutions is indicated in column 6. The total grid counts shown in column 7 is simply the product of the grids per frame in column 5 and the frame count in column 6. Note that the grid counts do not include any allowance for "stacking" grids to increase their effective thickness, nor the possibility of making two dimensional apertures by combining one dimensional grids.

The aperture sizes given in column 8 are determined by the product of the angular resolution and effective collimator length (3m in most cases).

The final column, identified as Critical Alignment Count (CAC) is a measure of the number of potential degrees of freedom associated with the metering structure whose preflight alignment must be maintained to a few microns during launch in order that the collimator response not be affected.

A number of assumptions are involved.

- (1) Relative dimensions within a grid are maintained at all times.

- (2) Frame to frame coalignment can be re-established by in-flight calibration.
- (3) Displacements parallel to the collimator axis are negligible.
- (4) Only the 4" resolution frames are considered. The larger tolerances that could be associated with other frames are not as difficult to maintain.

Building up a multigrid collimator, the position of the last grid is not critical. X and Y displacements of the first grid are not critical since they merely define the collimator axis. Rotation of the first grid relative to the last is critical, however, since it could degrade the effective response of individual subcollimators. Thus the first and last grids contribute 1 and 0 respectively to the CAC. In the case of two dimensional inner grids, excessive displacement in either X or Y directions or rotation degrades the response and so they each have 3 degrees of freedom which must be maintained. One dimensional inner grids contribute only 2 to the CAC since displacements parallel to the linear apertures are not critical. As an example, for the pencil beam system,

$$\text{CAC} = 16 \text{ (frames)} \times (1 \text{ (first grid)} + 3 \times 8 \text{ (inner grids)}) = 400.$$

The CAC for the other systems are similarly determined. Note that the scatter-hole and pin hole systems are largely immune to such alignment requirements. Also the periodic systems, with their fewer grids, have a lower critical alignment count than non-periodic systems.

C. Detector Characteristics

Characteristics of the detectors required by each of the reference systems are indicated in Table V-3.

Time and spectral resolution requirements are not indicated as these are largely independent of the collimation scheme as discussed in Section III. Thus the role of detector characteristics on the tradeoff is largely based on their

TABLE V-3 DETECTOR CHARACTERISTICS

System	Collimator Angular Resolution	Subcollimator Count	Spatial Resolution Requirements	
			FWHM	Type
1. Pencil Beam	4"	1	-	B
2. Multielement Pencil Beam	4"	32	-	B
3. Multielement Collimator Array	4"	1024	2mm	D2
4. Imaging Collimator	4"	-	~6mm	C2
5. Periodic MECA	4"	1024	2mm	D2
	128"	200	2mm	D2
6. Foveal System	4"	64	2mm	D2
	32"	9		
	1.6'	9		
	4.8'	9		
	14.4'	9		
7. Fan Beam Modulation Collimator	4"	6	-	B
	64"	4		
8. Multiple Fan Beams	4"	32x6	2mm	D2
	64"	32x4		
9. Rotating Modulation Collimator	4"	2	-	B
	64"	2		
10. Scatter-hole Camera	4"	-	~60μm	C2
11. Scatter-hole and Mask System	4"	(1.7x10 ⁵)	~1mm	D2
12. Scatter-strip and Mask	4"	(2.8x10 ³)	~1mm	D1
13. Pin hole	4"	-	~8mm	C2
14. Remote Scatter-hole	4"	-	~2mm	C2

spatial resolution.

The different types of spatial resolution requirements are indicated in the last column.

B - Background suppression is the driver for the detector spatial resolution in these systems where spatial sensitivity is not required for imaging purposes.

C2 - A two-dimensional continuous position sensitivity is most appropriate for these systems.

D1(D2) - One (two) dimensional discrete subcollimators require the detector to merely identify which subcollimators a photon passed through. The number of such subcollimators is indicated in column 3.

The FWHM spatial resolution requirements are shown in the fourth column. Digitizing the position of photon counts to the 2 mm quoted for systems with discrete subcollimators allows the 5 mm dead lane between subcollimators to ensure good subcollimator to subcollimator isolation without much sacrifice of effective area. The 6 mm resolution associated with the Imaging Collimator and the 8 mm of the Pin Hole system each corresponds to an angular resolution contribution of 1". Note that only in the case of the scatter hole camera is the spatial resolution requirement impractical for proportional counters.

D. Sensitivity

Table V-4 displays the factors entering into estimates of the sensitivities of the reference systems.

The third column indicates the gross collimator area associated with the collimators of each angular resolution. In most cases this comes to 60% of the 1m x 1m collimator envelope, with the remaining 40% required for structural purposes, etc. For the Rotating Modulation Collimator this is reduced by an additional factor of $\pi/4$ so that the four circular collimators can fit within the 1m x 1m envelope. The

TABLE V - 4 Sensitivity*

System	Collimator Angular Resolution	Gross Collimator Area	Gross Area for Image Element	Transmission	Transmitting Area per Image Element	Duty Cycle	λ_{LIE}	λ_{DPS}	λ_{XS}	λ_{CPS}	λ_{MAX}	Approximate Scaling of Sensitivity
1. Pencil Beam	4"	6000	6000	.141	846	1/1024	0.83	0.83	(10 ⁻¹)	846	846	G(R/V) ²
2. Multielement Pencil Beam	4"	6000	174	.141	24.5	1/32	0.77	0.77	(10 ⁻¹)	24.5	24.5	G(R/V) ²
3. Multielement Collimator Array	4"	6000	3.69	.141	0.52	1	0.52	0.52	(10 ⁻¹)	0.52	0.52	G(R/V) ²
4. Imaging Collimator	4"	6000	-	.141	-	1	0.78	0.78	(10 ⁻¹)	0.78	0.78	G(R/V) ²
5. Periodic MECA	4" 128"	4500 3500	2.55 5.01	.141 .245	0.36 1.2	1 1	0.36 1.2	0.36	1.2	0.36	1.6	G(R/P) ²
6. Foveal System	4" 32" 1.6" 4.8" 14.4"	4500 375 375 375 375	62.2 35.5 35.5 35.5 35.5	.141 .231 .243 .248 .249	8.8 8.2 8.6 8.6 8.8	(1) 1 1 1 1	8.8 8.2 8.6 8.6 8.8	8.8	(10 ⁻¹)	8.8	43	G(R/V) ²
7. Fan Beam Modulation Collimator	4" 64"	4500 1500	700 375	.375 .490	262 184	1/32 1/32	0.2 5.7	49	23	1575	2310	G R/P
8. Multiple Fan Beams	4" 64"	4500 1500	16.8 8.54	.375 .490	7.0 4.2	1 1	7.0 4.2	42	17	7.0	59	G R/P
9. Rotating Modulation Collimator	4" 64"	2356 2356	1178 1178	.375 .490	442 577	1/32 1/32	13.8 18.0	28	36	28	2038	G R/P
10. Scatter-hole Camera	4"	6000	-	.235	-	1	-	1300	1300	1300	1300	G
11. Scatter-hole and Mask System	4"	6000	-	.00023	-	1	-	1.3	1.3	1.3	1.3	G(R/D) ²
12. Scatter strip and Mask	4"	4243	-	.0103	2.57	1	5.13	41	41	41	41	G R/D
13. Pin Hole	4"	8.6	-	.25	2.15	1	2.15	2.2	(10 ⁰)	2.2	2.2	G(R/V) ²
14. Remote Scatter-hole	4"	6000	-	.235	-	1	-	1400	1400	1400	1400	G

* All areas are in cm².REPRODUCIBILITY OF THE
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scatter-strip and mask system is reduced by a factor of $1/\sqrt{2}$ to allow for a "packing problem" uniquely associated with this system. This system requires optimized detector spatial resolution perpendicular to the linear apertures which in turn determines the relative orientation of the proportional counter cathode and/or anode wiring. Fitting six rectangular proportional counters with orientations corresponding to the six grid orientations would not permit complete utilization of the 1m x 1m envelope. The factor of $1/\sqrt{2}$ is a worst case assumption. The 8.6cm^2 entry for the pin hole system is just the area of the 3.3cm diameter aperture.

The gross area indicated in column 4 is just the Gross Collimator Area divided by the Subcollimator Count (Table V-3) with an allowance of $2\frac{1}{2}$ mm on each edge to provide a 5 mm wall isolating adjacent subcollimators. As illustrated by Figure III-3,

$$\text{Gross Area per detector} = \left(\sqrt{\frac{\text{Gross Collimator Area}}{\text{Subcollimator Count}}} - 0.5 \right)^2$$

The collimator transmission, indicated in column 5 is a particularly significant factor since it is proportional to the source to background count ratio. As indicated in Section III, with the error budget of 9.7 microns, the transmission of 4" resolution collimators is 0.375 and 0.141 for the one and two dimensional configurations, respectively. The same error budget combined with the coarser collimators permits the higher transmissions shown for such cases. The maximum transmission of self-supporting random hole grids is 0.235 if no two holes are adjacent (Blake, 1976). For the scatter hole and mask system, the first grid transmission of 0.235 is significantly reduced by the low transmission, $(58.2\mu\text{m}/1862\mu\text{m})^2 = 9.8 \times 10^{-3}$, of the detector mask to yield the effective transmission of 2.3×10^{-4} . For the scatter-strip and mask systems the corresponding transmissions of the random strip and mask are 0.33 and 0.031 respectively resulting in a combined transmission of 0.0103. The transmission of 0.25

adopted for the pin hole system is due to the detector collimation required for background suppression.

The transmitting area per image element is the product gross area per subcollimator and the transmission.

Another significant parameter, the duty cycle, is indicated in column 7. It is the ratio of the time averaged effective area (or count rate) to the maximum instantaneous area (or count rate), and is unity except in the case of rotating of mechanically scanned collimators. It is important because low values of this duty cycle aggravate the dynamic range problem. Duty cycles assigned to the scanning or rastering systems in Table V-4 are slight overestimates since no allowance is made for dead time due to scan reversals, etc. Also for sources larger than 32" in extent, the foveal system duty cycle would be reduced appropriately.

A_{EIE} , the effective area per imaging element, is the product of the transmitting area per image element and the duty cycle. It represents, for example, the effective area for each fan beam orientation or for each of the 4 rotating modulation collimators.

A_{DPS} , the effective area for distinguishing point sources is an important measure of sensitivity. It represents the total time averaged effective area of the high resolution collimators for each system. The product of A_{DPS} , incident flux and detector and window efficiency is the total count rate associated with 4" collimators. Note that A_{DPS} itself includes no allowance for background, window transmission, detector efficiency or deconvolution effects. Although the relative sensitivity of the different systems is not uniquely determined by A_{DPS} , it forms a very useful measure of sensitivity, one which can be readily converted to a count rate as indicated above.

In view of the discussion in Section II on burst occurrence frequencies, it is worth noting that a system that is 4 times

as sensitive as another can expect to observe $4^{.8} \approx 3$ times as many bursts at a given level of detail.

A_{DPS} equal to A_{EIE} in most cases.

(Elsewhere A_{EIE} is multiplied by the number of fan beams or high resolution rotating collimators.) In the case of the scatter hole and scatter strip and mask systems A_{DPS} is the product of the gross area per subcollimator, number of subcollimators and transmission. For the remote scatter hole system, A_{DPS} is the product of the gross collimator area and the transmission.

A_{XS} is the effective area for extended solar sources (assumed $> 2'$ in extent). For systems with less than full sun field of view, this value is dependent on source size and scanning technique used. Order of magnitude estimates for these cases are indicated in brackets. For the others, A_{XS} is calculated similarly to A_{DPS} except the coarse resolution collimators were used, where applicable.

A_{CPS} is the effective area with which cosmic point sources could be viewed with the high resolution collimators. It is the same as A_{DPS} in all cases, except for the scanning systems whose mechanical scan is assumed not to be used in such cases. The same cautionary notes about background determination and deconvolution apply here as in the case of A_{DPS} .

A_{MAX} is the maximum area that can instantaneously view a point source. It is relevant in determining the total count rate from a source if spatial information were not important and in estimating of the upper limit of instrument count rates, summed over all detectors.

The final column shows how the sensitivity (i.e. A_{DPS}) would scale from the tabulated values if different choices of the angular response parameters had been made. The scaling

is approximate in that it does not allow for the effects of deconvolution, error budgets, subcollimator separation, etc. which would enter into the calculation in second order, nor does it indicate that some particular choices might be impractical to implement efficiently in practice. There are significant differences among the different systems in their scaling sensitivity, so that this comparison is an important one, particularly when the uncertain nature of some of the estimates of solar parameters is recalled, and the reflight and refurbishment potential of shuttle facilities is noted.

G - Sensitivity is proportional to the gross collimator area in all cases.

R - FWHM resolution.

V - Field of view.

P - Period of the high resolution collimators.

D - Detector spatial resolution.

E. Time Resolution and Telemetry

Table V-5 indicates some of the time resolution and telemetry considerations for each of the reference systems. The second column indicates the basic limitation on the time resolution of each system. In most cases this limitation is due simply to counting statistics. Clearly this limitation will be strongly energy and flare dependent but in any situation will be less severe for systems with more sensitivity. For mechanically scanned or rotated systems, the ultimate time resolution is also limited by the scan or rotation rate. For the foveal system the limitation is source and program dependent if the foveal elements have to be "time shared" among more than one hot spot in the source.

The estimated time resolution is indicated in the third column. For statistics limited systems, 0.1 seconds is indicated, since this would be appropriate if the collimator

TABLE V-5 TIME RESOLUTION AND TELEMETRY

	System	Time Resolution Limitation	Time Resolution (sec)	Image Susceptibility to Source Changes	Number of Spatial Bins	Number of Time Bins/Sec	Max Telemetry Rate ($\times 10^6$ BPS)	
1.	Pencil Beam	0.5 sec single scan	16	extreme	64	256	0.88	T
2.	Multielement Pencil Beam	0.5 sec single scan	0.5	yes	64	256	0.88	T
3.	Multielement Collimator Array	statistics	<0.1	no	1024	10	1.2	T
4.	Imaging Collimator	statistics	<0.1	no	1.6×10^4	10	1.5	T
5.	Periodic NECA	statistics	<0.1	no	1224	10	1.3	T
6.	Foveal System	statistics, source extent	(<0.1)	For large sources (>32") only	100	10	0.35	B
7.	Fan Beam Modulation Collimator	2 sec single scan	<0.1 (2)	yes	64	1.0×10^3	0.88	T
8.	Multiple Fan Beams	statistics	<0.1	no	320	10	1.1	T or B
9.	Rotating Modulation Collimator	60 rpm rotation rate	0.5	yes	48	1.7×10^4	0.88	T
10.	Scatter-hole Camera	statistics	<0.1	no	1.8×10^6	10	2.6	T
11.	Scatter-hole and Mask System	statistics	<0.1	no	1.7×10^5	10	1.8	T
12.	Scatter strip and Mask	statistics	<0.1	no	2.8×10^3	10	1.4	T
13.	Pin Hole	statistics	<0.1	no	1.6×10^4	10	1.5	T
14.	Remote Scatter-hole	statistics	<0.1	no	1.5×10^5	10	1.8	T

were dithered with a pointing system with 5 Hz bandwidth. In other cases this limit follows directly from the scan/rotation rates. Note that even though the fan beam modulation collimator single scan time is 2 seconds across the whole sun the high resolution elements have an effective time resolution that is much better since the periodic response of each subcollimator ensures that it will view a given point many times during a scan. The time resolution remains 2 seconds, however for the coarse, non-periodic subcollimators. Note that the time resolution of 16 seconds is a severe drawback for the pencil beam system. Note also that if the scan/rotation rates assumed here are overestimates, the adequacy of time resolution for some systems would have to be reconsidered.

The fourth column indicated whether the imaging is susceptible to source time variations comparable to the time resolution.

The last three column review the reference systems telemetry requirements. There are two basic techniques which could be used to encode the data of an instrument such as this, viz., binning and tagging. Tagging implies that each detected photon is assigned a telemetry word which indicates its energy and appropriate detector spatial information. Its arrival time is implicit in its position in the data stream. Assuming a maximum instrument count rate of 80,000 counts per second (2×10^4 counts per second in each of 4 proportional counters) and 5 bit energy label (i.e., 32 channels), we have Max. Tagging Bit Rate = $80,000 \times (5 + \log_2 (\text{No. of Spatial Bins}))$.

Alternatively the data may be binned so that each photon count is added to an appropriate spatial/energy bin, which is then read out periodically, so that

$$\text{Binning Bit Rate} = 32 \text{ (energy channels)} \times \text{Number of spatial bins} \\ \times \text{Number of Time bins/seconds} \times \text{Bits per bin}$$

Assuming 20,000 counts per second as an upper limit to any bin sets the Bits per bins = $\log_2 (20,000/\text{Time bins per second})$.

The number of spatial bins and time bins per second are shown in columns 5 and 6. The minimum of the tagging or binning bit rates is shown in the last column with a T or B to indicate which was used.

Some caveats on this estimate should be noted.

- (1) No housekeeping or aspect data is included.
- (2) These represent peak, not average telemetry rates.
- (3) No attempt has been made to compress the telemetry or to take advantage of the expected data characteristics in order to achieve a more efficient use of telemetry.
- (4) A more optimized strategy may involve a combination of binning and tagging.

Thus the bit rate quoted is a very conservative upper limit to the telemetry requirement in each case. Apart from the foveal system and scatter hole systems, the range of telemetry rate estimates is relatively small, and not incompatible with a shuttle facility.

F. Miscellaneous

Some other considerations which may enter into the overall tradeoff among collimation systems are outlined in Table V-6.

The second column recalls some of the subsystem requirements not common to all of the systems. The third column points out operational tasks required of the pointing system in addition to sun or active region pointing. Systems requiring pretargeting to an active region are indicated next. The final columns are those systems which would be inherently adaptable to detectors with less spatial resolution than possible with proportional counters. Solid state detectors or scintillation detectors would provide an attractive way to

TABLE V-6 MISCELLANEOUS

	System	Subsystem Requirements	Additional Pointing System Requirements	Pretargeting Required	Suitable for Solid State or Scintillation Detectors	Suitable for Focal Plane Instrumentation with Poor Spatial Resolution
1.	Pencil Beam	MGC*	Rapid raster	Yes	Yes	Yes
2.	Multielement Pencil Beam	MGC	Rapid scan	Yes	Yes	Yes, if scan mode changed.
3.	Multielement Collimator Array	MGC	Dither	Yes	Yes, if fewer subcollimators	No
4.	Imaging Collimator	MGC	Dither	Yes	No	No
5.	Periodic MECA	MGC	Dither	No	Yes, if fewer subcollimators	No
6.	Foveal System	MGC, Response loop	Responsive to burst location & extent.	No	Yes	Yes
7.	Fan Beam Modulation Collimator	MGC	Rapid scan	No	Yes	Yes
8.	Multiple Fan Beams	MGC	Dither	No	Yes	No
9.	Rotating Modulation Collimator	MGC, rotation drive	-	No	Yes	Yes
10.	Scatter-hole Camera	high spatial resolution detector	Dither	No	No	No
11.	Scatter-hole and Mask System	-	Dither	No	No	No
12.	Scatter-strip and Mask	-	Dither	No	No	No
13.	Pin hole	subsattellite	-	Yes	Yes	Yes, with suitable operational modes
14.	Remote Scatter-hole	subsattellite or tethered boom	-	No	Yes, if appropriate parameter changes	No

* MGC - multigrid collimator

extend the high energy detection efficiency but could not be used with collimation systems requiring (continuous) spatial resolution better than a few centimeters. Similarly focal plane instrumentation such as X-ray polarimeters would not be inherently adaptable to systems requiring appreciable spatial resolution. Collimation systems with gross subcollimator areas $\sim 10^2 \text{ cm}^2$ could be adaptable to such instrumentation, however.

VI. TRADEOFF SUMMARY

Table VI - 1 summarizes some of the more significant tradeoff considerations that have been discussed in previous sections. Before considering the relative merits/demerits of the reference systems, the definition and significance of the criteria in the columns will be reviewed.

A. Criteria Review

The second column indicates those systems which in the reference configuration had fields of view limited to about 2' x 2' and those with full sun fields of view. Configurations with less than full sun field of view require pretargeting and risk missing all or part of flares in other active regions.

This third column, A_{DPS} , indicates the time-averaged effective area for imaging a point source within the high resolution field of view. Note that this area does not make any allowance for window transmission losses or detector inefficiency so that at a particular energy, all the effective areas must be reduced accordingly.

The duty cycle indicated in the fourth column is the ratio of the time averaged effective area to the maximum instantaneous effective area. Small values of this ratio aggravate the dynamic range problem.

Transmission, given in the fifth column, represents the collimator transmission for an on-axis source. The source/background-count ratio is proportional to this factor so it is relevant at the higher energies where background considerations become serious (see Figures II - 1, II - 2).

Image formation notes whether two dimensional images are directly formed by the collimator or whether a deconvolution algorithm needs to be used, as is the case with indirect image formation.

Systems whose images are susceptible to time variations are indicated in the seventh column. In such cases the time

TABLE VI-1 TRADEOFF SUMMARY

System	Field of View*	A _{DPS} (cm ²)	Duty Cycle	Transmission	Image Formation	Imaging Susceptibility to Time Variations	Critical Alignment Count	Unique Design Areas
1. Pencil Beam	128x128"	0.83	1/1024	.141	direct	yes, very	400	-
2. Multielement Pencil Beam	128x128"	0.77	1/32	.141	direct	yes	400	-
3. MECA	128x128"	0.52	1	.141	direct	no	400	-
4. Imaging Collimator	128x128"	0.78	1	.141	direct	no	400	-
5. Periodic MECA	PFS	0.36	1	.141	direct	no	156	-
6. Foveal System	32"x32", FS with limited resolution 8.8		1	.141	direct	for large sources (> 32") only	300	response loop
7. Fan Beam Modulation Collimator	PFS	49	1/32	.375	direct for projections indirect for 2D	yes	108	-
8. Multiple Fan Beams	PFS	42	1	.375	"	no	108	-
9. Rotating Modulation Collimator	FS	28	1/32	.375	indirect	yes	72	rotation drive
10. Scatter-hole Camera	PFS	1300	1	.235	indirect	no	0	detector with ~60 micron resolution
11. Scatter-hole and Mask System	FS	1.3	1	.00023	indirect	no	0	-
12. Scatter-strip and Mask	FS	41	1	.01	2 stage indirect	no	16	-
13. Pin-hole	128x128"	2.2	1	.25	direct	no	0	subsatellite
14. Remote Scatter-hole	FS	1400	1	.235	indirect	no	0	subsatellite or tether system

* FS = Full Sun

PFS = Periodic over the Full Sun

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variations must be more rapid than the mechanical scanning or rotation rate of the collimator.

Critical alignment count refers to the number of one dimensional alignment adjustments which must be maintained during launch for the system to suffer no degradation of its 4" imaging capability. Alignment adjustments relative to lower resolution elements or whose settings can be verified by in-flight calibration on cosmic sources are not included.

Finally the last column indicated the unique design areas where the more significant development aspects unique to a given collimator scheme are identified.

B. Tradeoff Discussion

The first five systems listed in Table VI - 1 all suffer from the potentially serious disadvantage of low sensitivity. Recalling that the peak flux for a "once-a-day" flare is ~ 2 photons/cm² sec above 20 kev, their effective areas of $< 1\text{cm}^2$ would not permit nonthermal imaging except perhaps by accepting a severe sacrifice of time resolution.

The foveal system would provide direct images with an order of magnitude improvement in sensitivity with the most serious drawbacks being some imaging susceptibility to time variations for sources larger than $\sim 32"$ in extent and the necessity of providing a microprocessor-controlled response loop between the detectors and pointing system.

The two fan beam systems offer a further increase in sensitivity compared to the foveal system. In addition, their transmission is higher and the critical alignment count somewhat less than with the foveal system. Some physical questions could be answered directly by the fan beam data while 2 dimensional images would require an additional data reduction stage. Comparing the two fan beam approaches, the multiple fan beams require a small penalty in effective area but have the advantages of (1) inherently high time resolution,

(2) lack of susceptibility to source time variations, (3) a less severe dynamic range problem and (4) no need for a rapid scanning motion. On the other hand the fan beam modulation collimator would be able to view cosmic point sources more effectively.

The rotating modulation collimator offers comparable sensitivity to the fan beam approaches but suffers from several relative disadvantages. First the indirectly formed image in this case must proceed through a somewhat more involved deconvolution procedure. Although it can provide a complete two dimensional image in principle, it does not, except in the simplest cases, permit as much spatial information to be apparent until after the deconvolution is complete. Second, it is susceptible to rapid source variations. Third, it requires development of a rotation drive system. Fourth, the low duty cycle accentuates the dynamic range problem. Its advantage over the fan beam systems is its formal potential for image completeness.

Although the scatter hole camera offers 2 orders of magnitude more sensitivity than the fan beam or RMC systems it requires a $\sim 1 \text{ m}^2$ detector with 2 dimensional spatial resolution of ~ 60 microns. Such detectors are not available at present.

The scatter-strip and mask system, however, has a factor of ~ 2 sensitivity advantage over the fan beam systems. The price paid for this advantage is a relatively low transmission and a more complex deconvolution task. In addition to its sensitivity advantage, alignment of such a system would be greatly simplified compared to fan beams.

The pin hole subsatellite approach, as configured in the reference system does not appear to offer any striking advantages. It has excellent potential, however, in its application to sub arc second and very high energy imaging, applications where conventional collimator structures would

not be feasible.

Combining the subsatellite and scatter-hole concepts as is done in the last system does offer a 2 order of magnitude sensitivity gain in addition to the other potential capabilities of the subsatellite approach. Although a high resolution collimator structure is not required, the need for a subsatellite or tethered boom system may be an overriding consideration.

The more viable systems that remain from the preceeding discussions are:

- (1) Foveal system
 - (2) Multiple fan beams
 - (3) Rotating modulation collimator
- and (4) Scatter-strip and mask system.

Among these four, the primary advantages and disadvantages may be summarized as follows.

Compared to the other three, the rotation modulation collimator has comparable sensitivity, but with a deconvolution requirement and a lower duty cycle which aggravates the dynamic range problem.

Comparing the foveal and multiple fan beam systems, the foveal system has a reduced, but perhaps adequate sensitivity, and the advantage of direct imaging. Its primary weakness is in its necessity to "time share" coverage if the burst extent were larger than its field of view of its high resolution elements.

This is not the case with the multiple fan beam system which views the whole sun at all times with good sensitivity but which does require a deconvolution step to produce two dimensional images.

Relative to the multiple fan beam system, the scatter strip and mask approach has the advantages of more sensitivity and simplified metering structure and grid requirements,

but at the expense of a more involved deconvolution procedure and much lower transmission which would seriously aggravate the background effects at higher energies. Improved detector resolution could ease the latter problem somewhat.

It should be noted that the detector and collimator requirements of the foveal and multiple fan beam systems are similar so that they could co-exist in the same collimator during a given mission or be easily interchanged from one flight to the next.

The scatter strip and mask approach would also be compatible with these two if an appropriate detector readout system were provided.

REFERENCES

- Blake, R.L., Burch, A.J., Fenimore, E., Puetter, R.: 1974, Rev. Sci., Inst., 45, 513.
- Blake, R.L., Santos, P.F., Barrus, D.M., Brubaker, W., Fenimore, E., and Puetter, R.: 1976a, Space Inst., in press.
- Blake, R.L., Barrus, D.M., and Fenimore, E., 1976b, Rev. Sci. Inst. 47, 899.
- Bradt, H., Garmire, G., Oda, M., Spada, G., Sreekantan, B.V., Gorenstein, P., and Gursky, H.: 1968, Space Sci. Rev., 8, 471.
- Brown, C.M.: 1972, Ph.D. dissertation, University of Chicago.
- Culhane, J.L. and Acton, L.W.: 1970, Mon. Not. Roy. Astr. Soc. 151, 141.
- Datlowe, D.W., Elcan, M.J. and Hudson, H.S.: 1974a, Solar Phys. 39, 155.
- Datlowe, D.S., Hudson, H.S., and Peterson, L.E.: 1974b, Solar Phys. 35, 193.
- Dicke, R.H.: 1968, Ap.J. 153, 101.
- Frost, K.J.: 1969, Ap.J. Lett. 158, L159.
- Gaarder, N.T., and Herman, G.T.: 1972, Computer Graphics and Image Processing, 1, 97.
- Gilbert, P.: 1972, J. Theor. Biol., 36, 105.
- Gordon, R., Bender, R., and Herman, G.T.: 1970, J. Theor. Bio., 29, 471.
- Hudson, H.S.: 1975, "Coronal Hard X-Ray Sources", presentation to FDT.

- Hudson, H.S.: 1976, "Pinhole Satellite", presentation to FDT.
- Kahler, S.W., Krieger, A.S. and Vaiana, G.S.: 1975, Ap.J. Lett. 199, L57.
- Kane, S.R. and Hudson, H.S.: 1970, Solar Phys. 14, 414.
- Kundu, M.R., Velusamy, T., Becker, R.H.: 1974, Solar Phys. 34, 217.
- McGrath, J.F. and Harwit, M., 1969, Applied Optics 8, 837.
- McIntosh, P.S., and Donnelly, R.F.: 1972, Solar Phys. 28, 444.
- Rust, D.M. and Hegwer, F.: 1975, Solar Phys. 40, 141.
- Schmidtke, G.: 1970, Applied Optics, 9, 447.
- Schnopper, H.W., Thompson, R.I. and Watt, S.: 1968, Space Sci. Rev. 8, 534.
- Svestka, Z.: 1976, "Solar Flares," Reidel Publ.
- Takakura, T., Ohki, K., Shibuya, N., Fujii, M., Matsuoka, M., Miyamoto, S., Nishimura, J., Oda, M., Ogawara, Y., and Ota, S.: 1971, Solar Phys. 16, 454.
- Van Beek, H.F., De Feiter, L.D., and de Jager, C.: 1974, Space Res. 15.
- Vorpahl, J.A.: 1972, Solar Phys. 26, 397.
- Vorpahl, J.A., Gibson, E.G., Landecker, P.B., McKenzie, D.L., and Underwood, J.H.: 1975, Solar Phys. 45, 199.
- Willmore, A.P.: 1970, Mon. Not. Roy. Astr. Soc 147, 387.

FIGURE CAPTIONS

Figure II-1 Differential Spectra

The top curve shows the differential spectrum of the incident X-ray flux for a typical thermal burst

(15×10^6 K, 3×10^{48} cm⁻³)

plus a "once-a-day" non-thermal burst (E^{-4} differential spectrum, 0.32 photons (cm² s keV)⁻¹ at 20 keV). The center curve shows the corresponding count rate spectrum that interacts in 40 atm - cm of Xenon after passing through an aluminum window with the property that 99% of its area is 0.1 g/cm² and 1% is 0.01 g/cm². The lower curve shows a representative background level. When count rates are estimated, it should be noted that the source spectrum is effectively lowered relative to the background spectrum by a factor equal to the transmission.

Figure II-2 Integral Spectra

The three curves are the integral spectra corresponding to the differential spectra shown in Figure II-1.

Figure III-1 Multigrid Collimator Principles

In panel A, simplified versions of two, three and four grid collimators are illustrated, with representative photon paths shown. Note that all apertures and walls are the same. In panel B, the angular response in each case is shown. In panel C, a 6 grid collimator is shown where the period is 32 times the FWHM resolution. Note that small displacements of the inner grids would have no effect on the angular response.

Figure III-2 Phased Array of Subcollimators

The top panel shows a three grid collimator divided into four subcollimators, each with a period four times the

resolution FWHM. The second panel shows the transmission of each subcollimator. The third panel illustrates the "uniformity of field" property whereby subject to the envelope, the summed transmission over all subcollimators is uniform. The bottom panel shows how the angular half peak contours repeat to give a wide field, high resolution coverage.

Figure III-3 Effective Area of Subcollimators

The effective area per subcollimator is shown as a function of the total number of such subcollimators in the 1m x 1m collimator envelope. Assumptions are: (1) 40% of the total area is devoted to structural purposes, etc. (2) A 5 mm wall is provided between each subcollimator (3) Transmission is 0.375 and 0.141 for the one and two dimensional cases, respectively. The deviation from straight lines is due to the walls between the subcollimators.

Figure III-4 Angular Resolution Limits

The energy dependence of the angular resolution limits are shown for a 3 m collimator. The diffraction curve represents the criteria discussed in the text. The grid transparency curve assumes the aperture is equal to one absorption length. The alignment curve assumes the aperture is equal to 10 μ m. Note that none of these limits are absolute. They merely represent regions where additional care needs to be taken or other tradeoffs considered.

Figure III-5 Dithering Simulation

The top panel shows an assumed source function. The second panel shows the simulated response of a fan beam system with the data put in 4" bins as is necessary with a stationary 4" FWHM collimator. The lower panel shows the response of an identical system with the data binned to 1" as would be possible if dithering or scanning were used. The

total number is 1000 in each case.

Figure IV-1 Direct Imaging Systems

Each column schematic illustrates a different approach to direct imaging. The top panel indicates the angular half peak contours in each case. The lower panel indicates the collimator scanning or rastering motion required. To simplify the figure, a field of view only 8 times the FWHM resolution is illustrated.

Figure IV-2 Imaging Collimator

A four grid imaging collimator is shown, along with photon paths corresponding to typical transmission maxima. Note that the apertures are slightly more closely spaced at the bottom than at the top.

Figure IV-3 Fan Beam Systems

The two columns schematically show how the fan beam systems view a source. The top figures illustrate the angular half peak contours while the lower panel shows the collimator scanning motion. To simplify the figure, only one set (orientation) of non-periodic fan beam is illustrated with a field of view only eight times the FWHM resolution.

Figure IV-4 Rotating Modulation Collimator

The top panel shows the transmission maxima of the fan beam collimator projected against the sky. Rotation of the collimator about its axis of rotation, R, means the alternate detector intermittently views a source, S. The resulting count rate plot is shown in the lower panel. Note that the number of maxima in a half revolution is twice the number of projected transmission maxima between the source and rotation axis.

Figure IV-5 Scatter-hole Camera.

A point source, S, illuminating a single random aperture grid, G., illuminates a spatially resolving detector, D.

Figure IV-6 Pin hole Subsatellite

Schematic view of a pinhole subsatellite positioned between the sun and detector system which would be on board the orbiter.

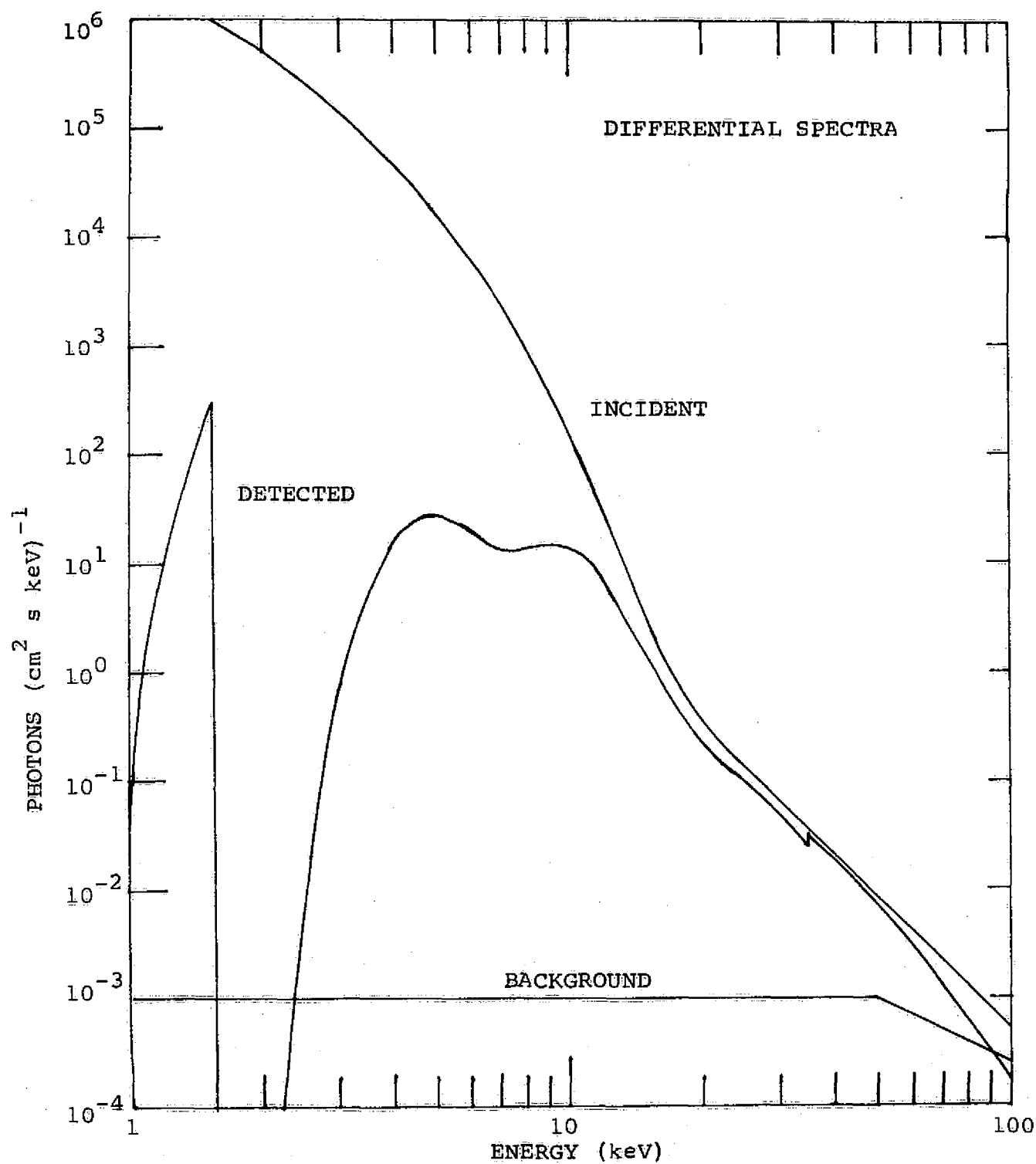


Figure II-1

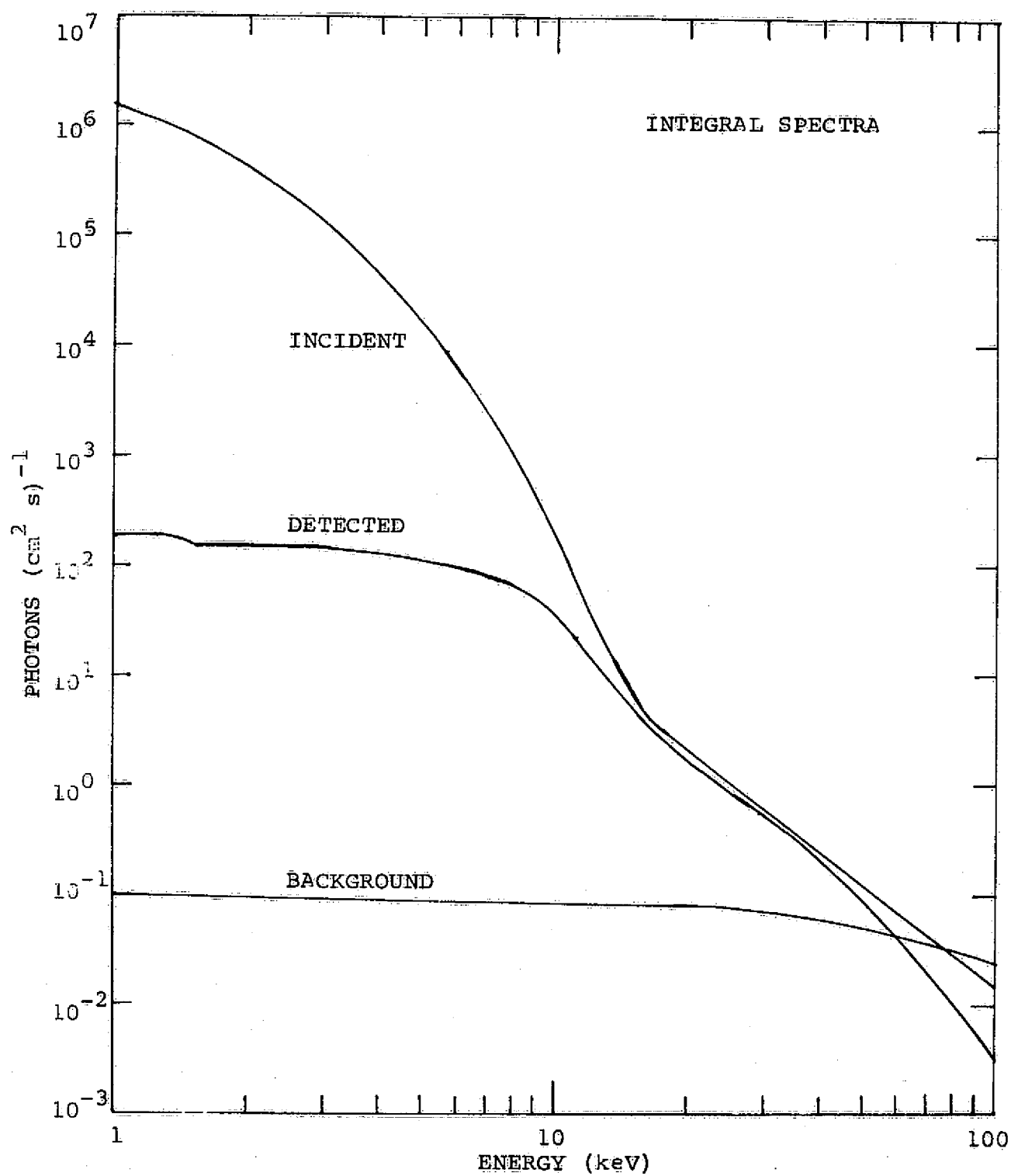
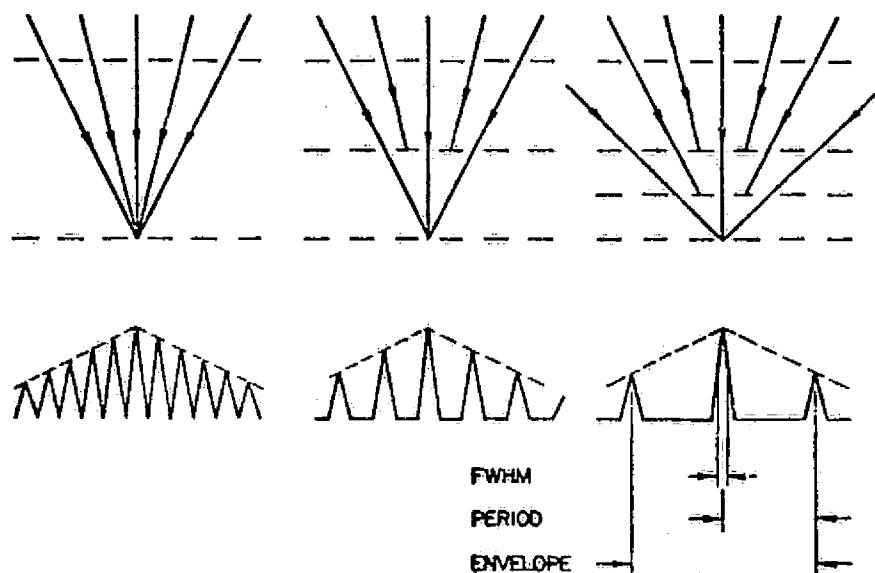


Figure II-2

MULTIGRID COLLIMATOR PRINCIPLES



Resolution FWHM $\approx$ (Aperture / Collimator length)

Period = Resolution FWHM $\times 2^{(\text{Grid count} - 1)}$

Envelope $\approx$ (Collimator width / Collimator length)

Figure III-1 a and b

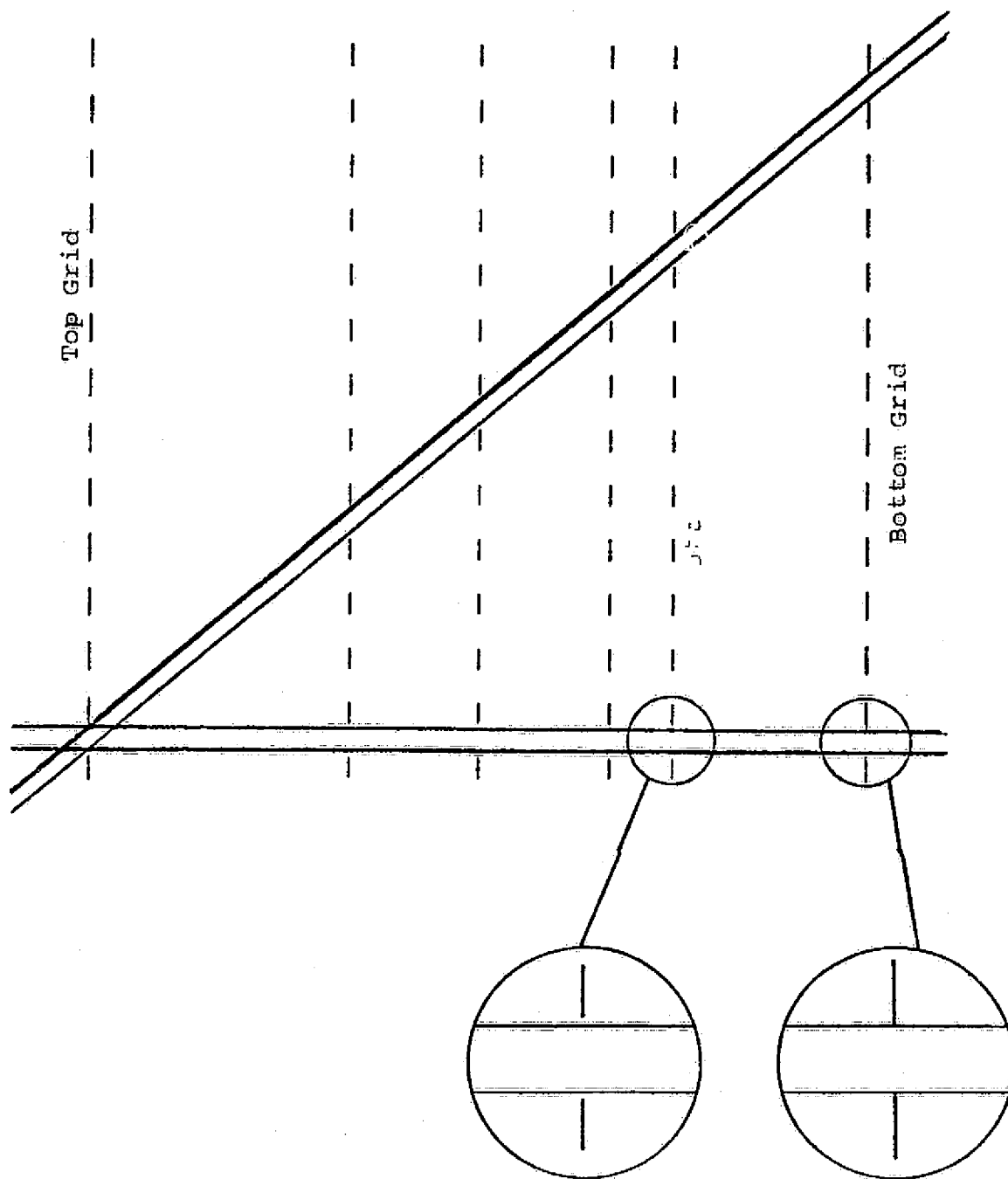
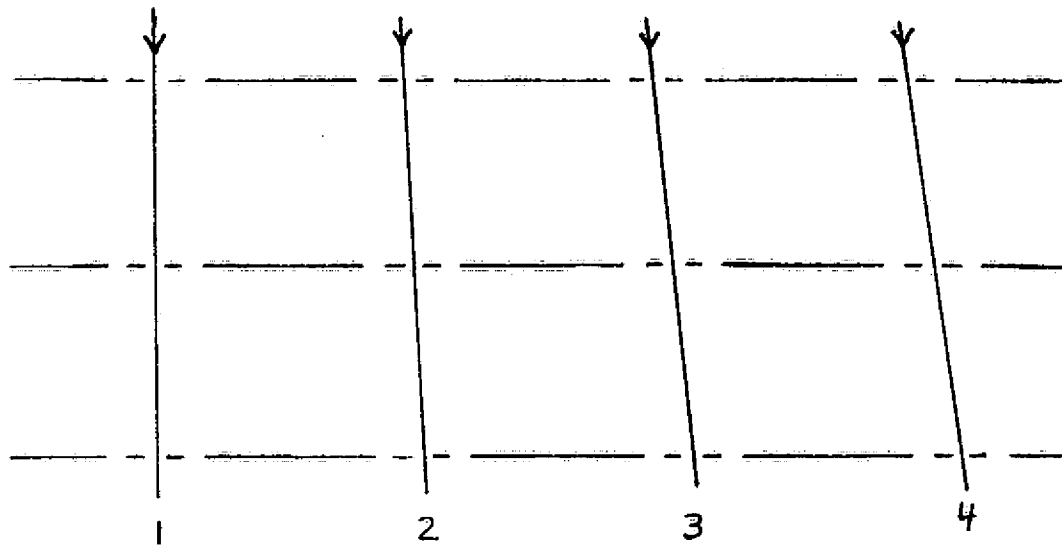


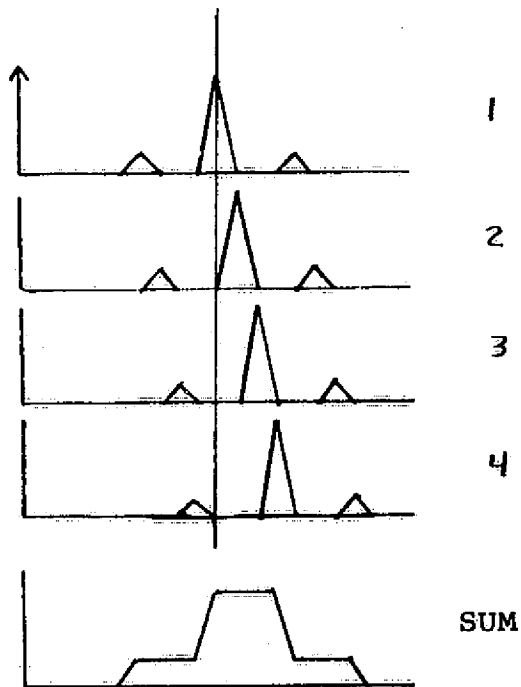
Figure III-1c

SUBCOLLIMATOR CONCEPT

Grid
Geometry



Transmission



Half-peak
Angular Response
Contours



Figure III-2

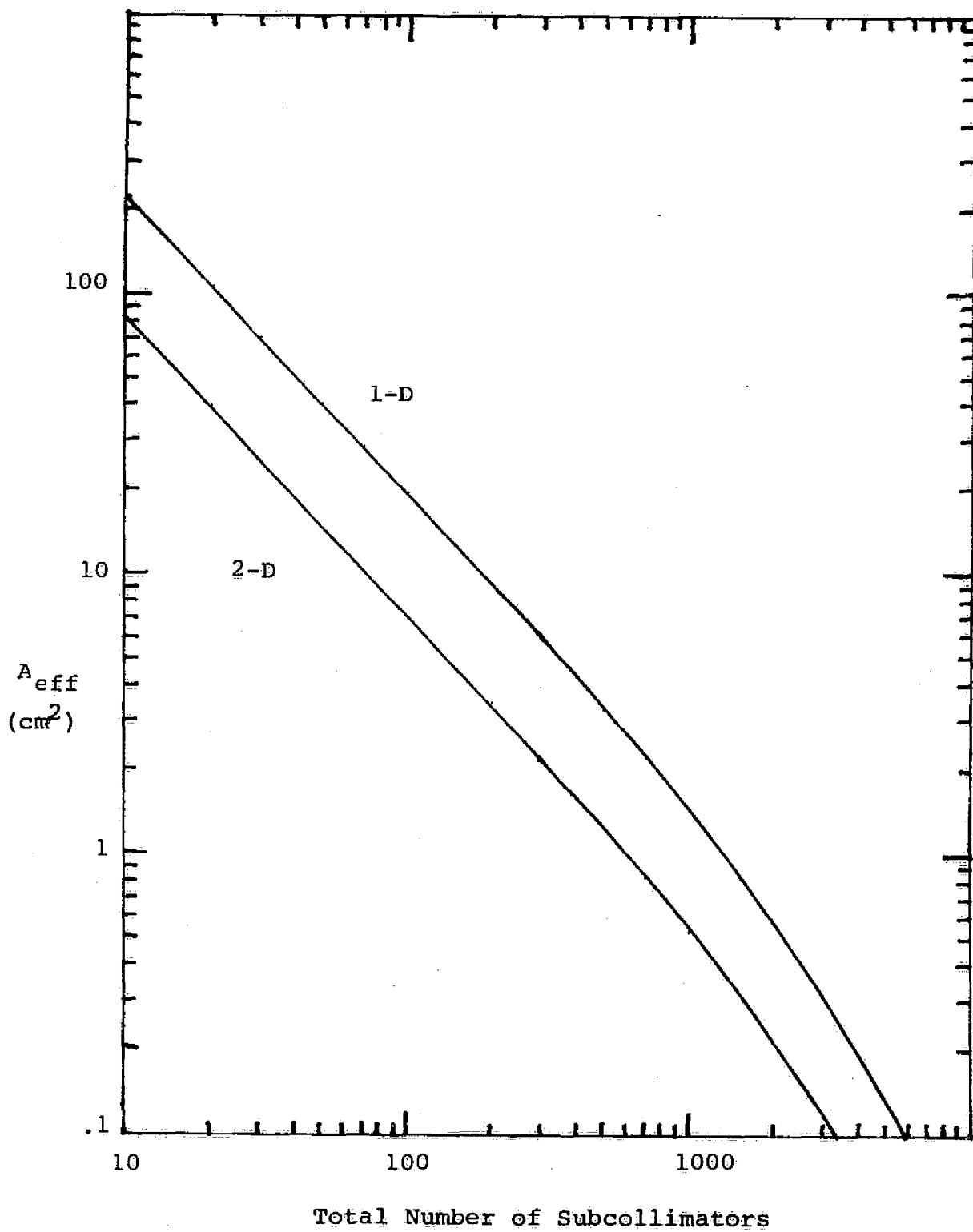


Figure III-3

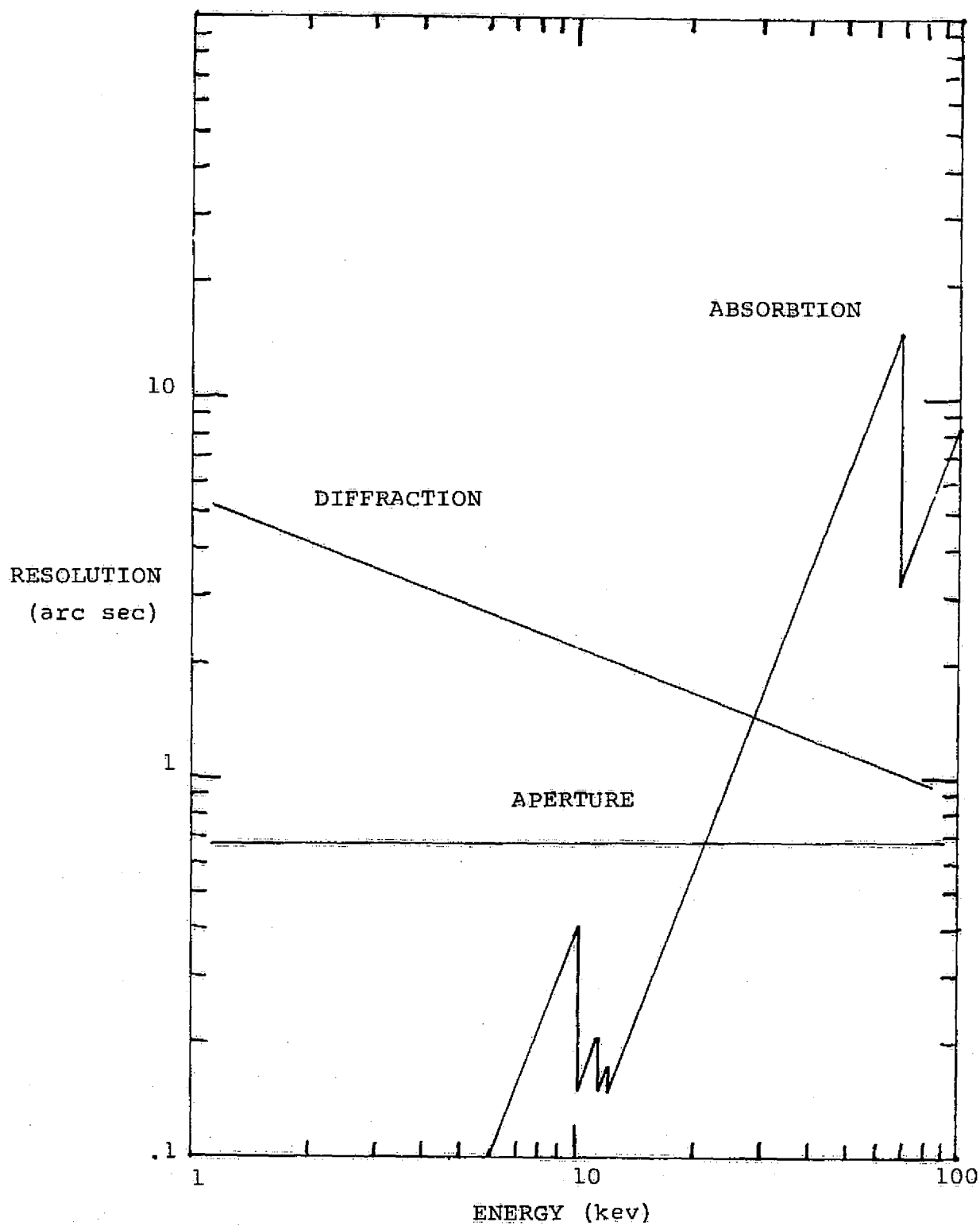


Figure III-4

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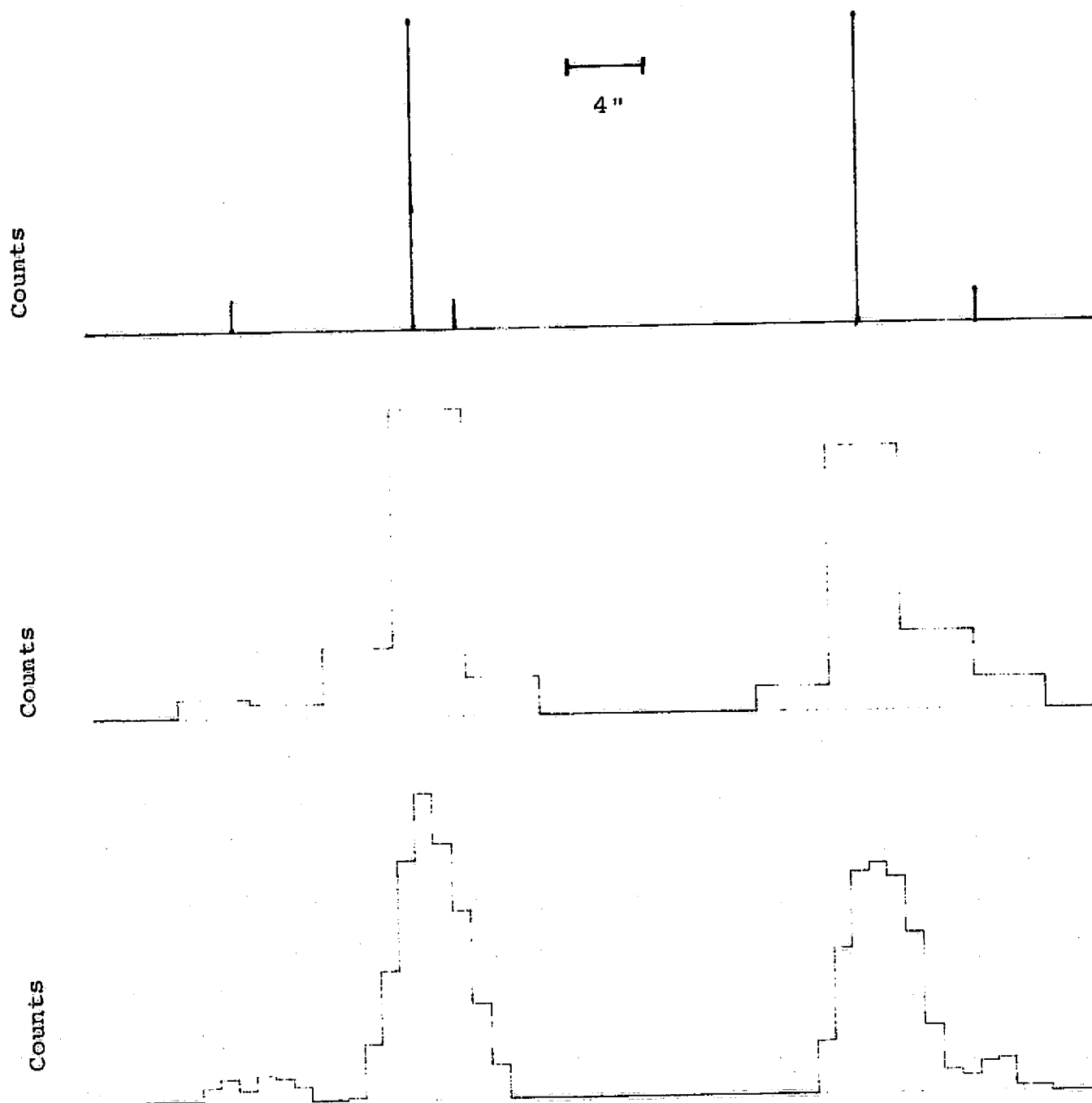
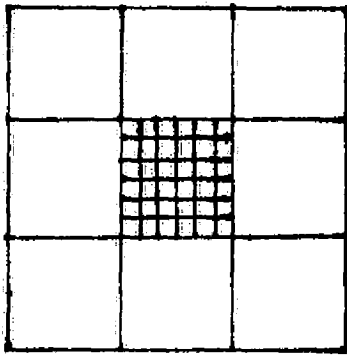


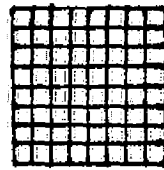
Figure III-5

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FOVEAL SYSTEM

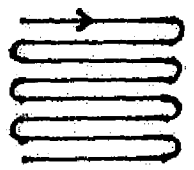


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MULTIELEMENT
COLLIMATOR ARRAY



MULTIELEMENT
PENCIL BEAM



PENCIL BEAM

Figure IV-1

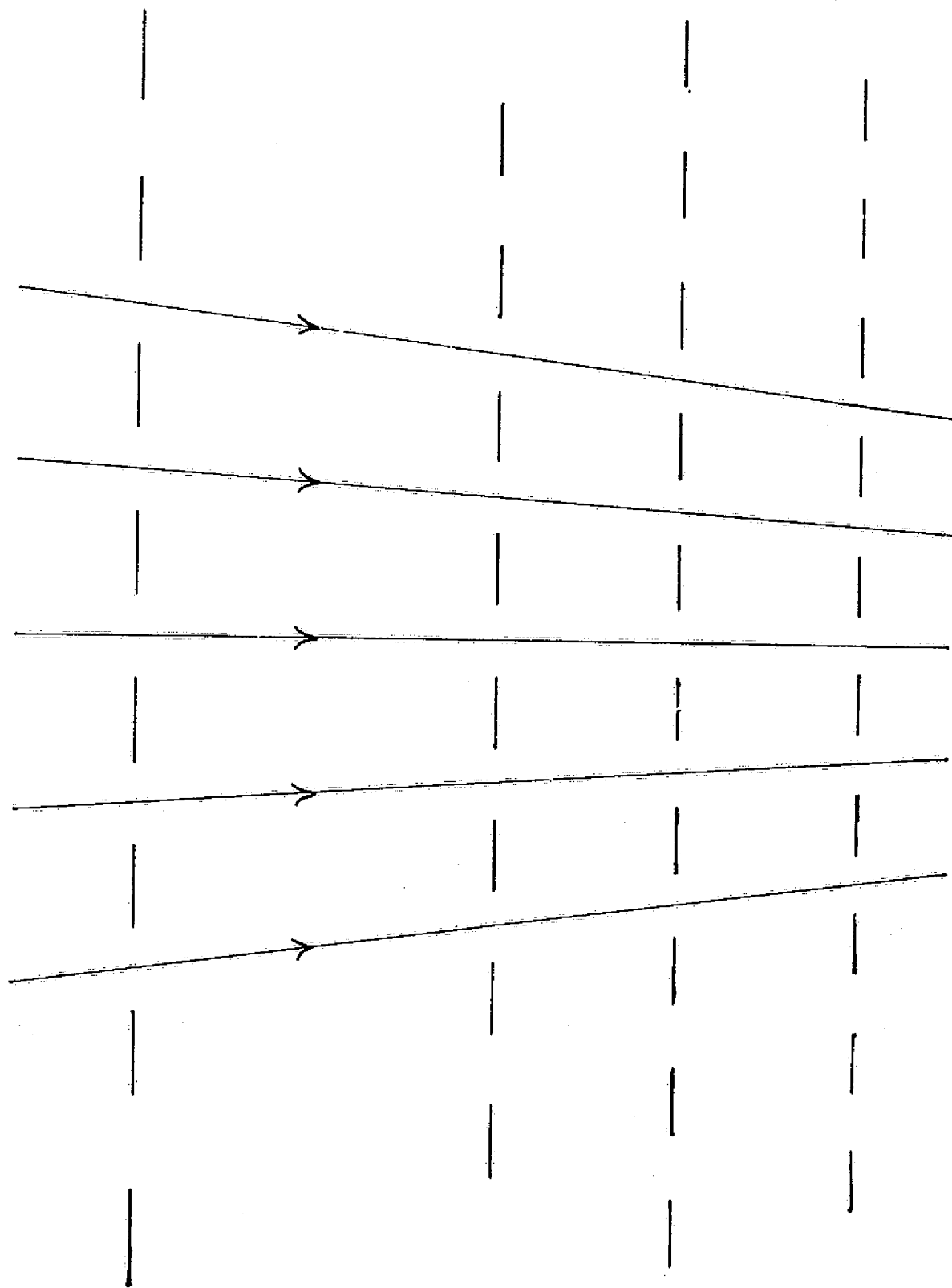
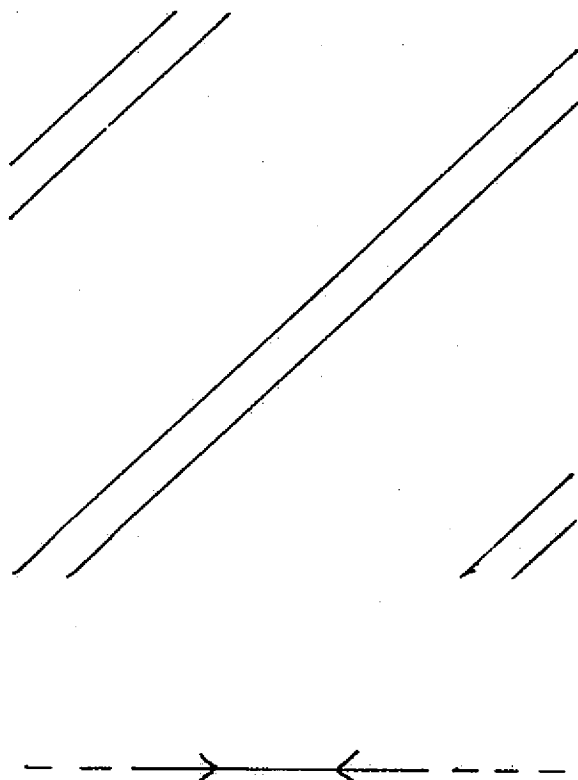


Figure IV-2

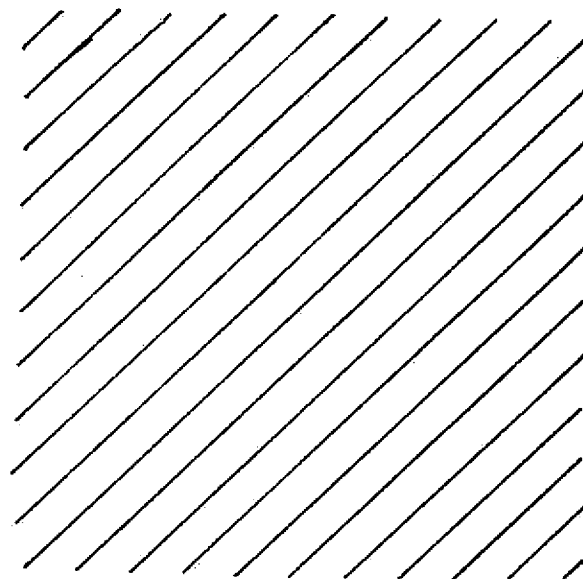
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III-71

Figure IV-3



FAN BEAM MODULATION
COLLIMATOR



none

MULTIPLE FAN BEAMS

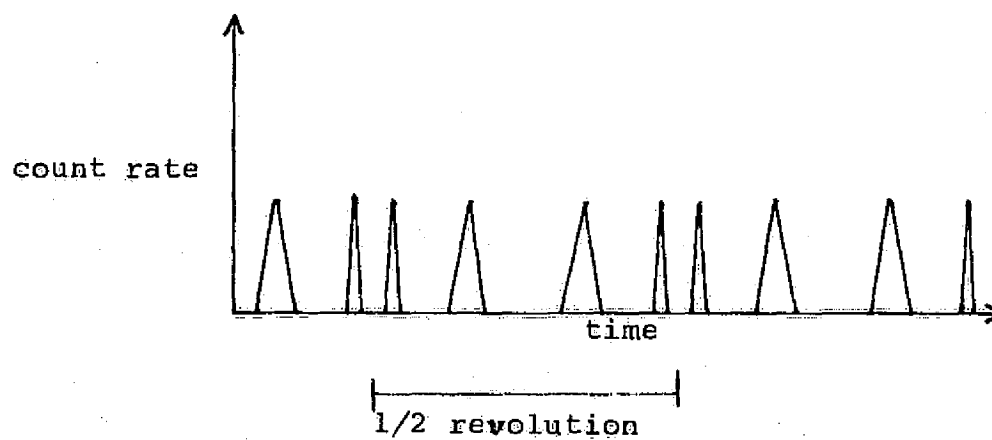
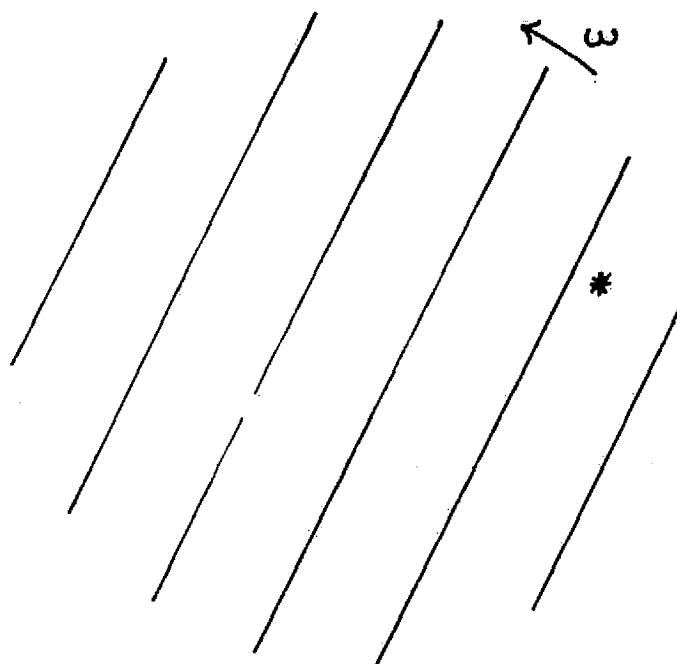


Figure IV-4

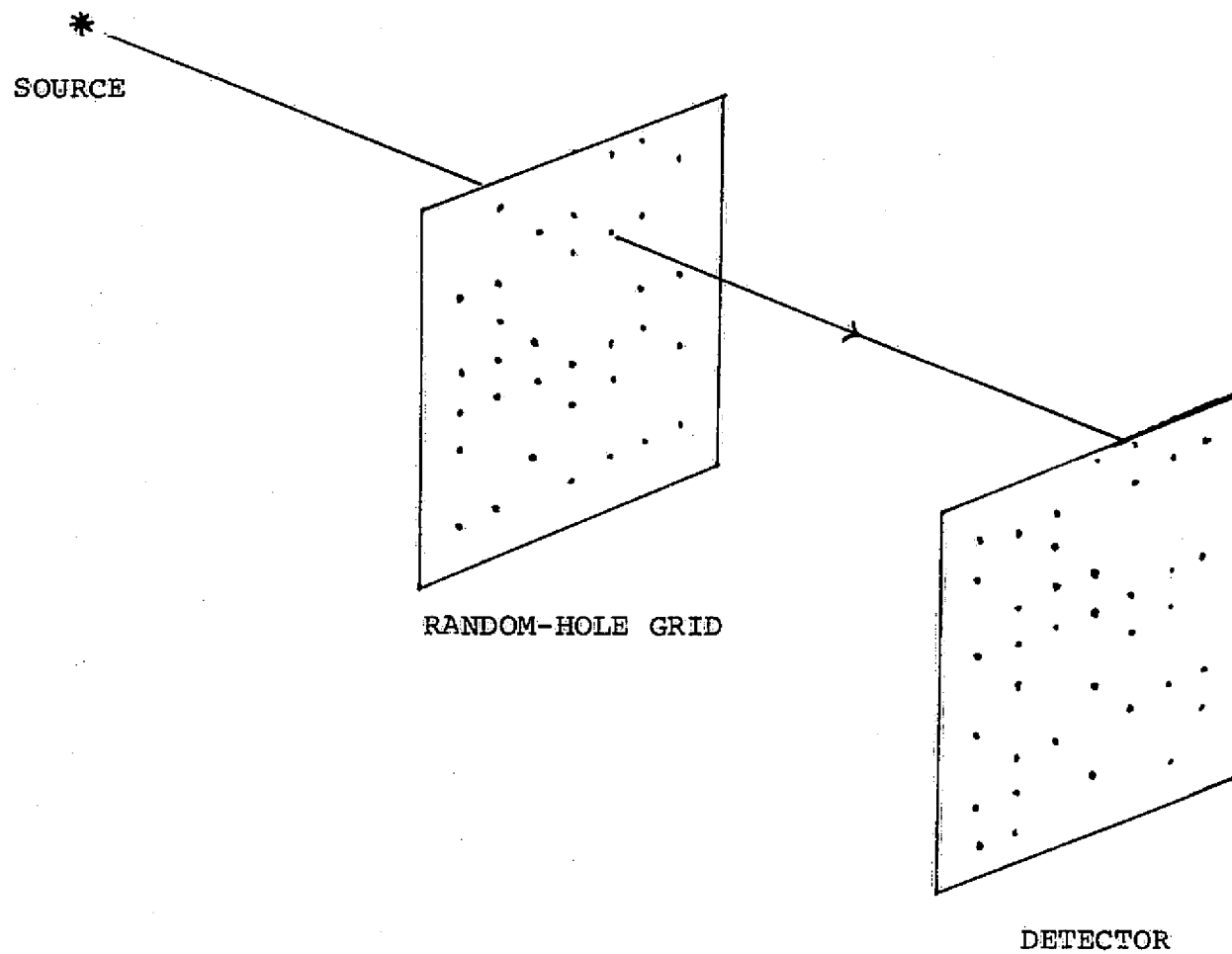


Figure IV-5

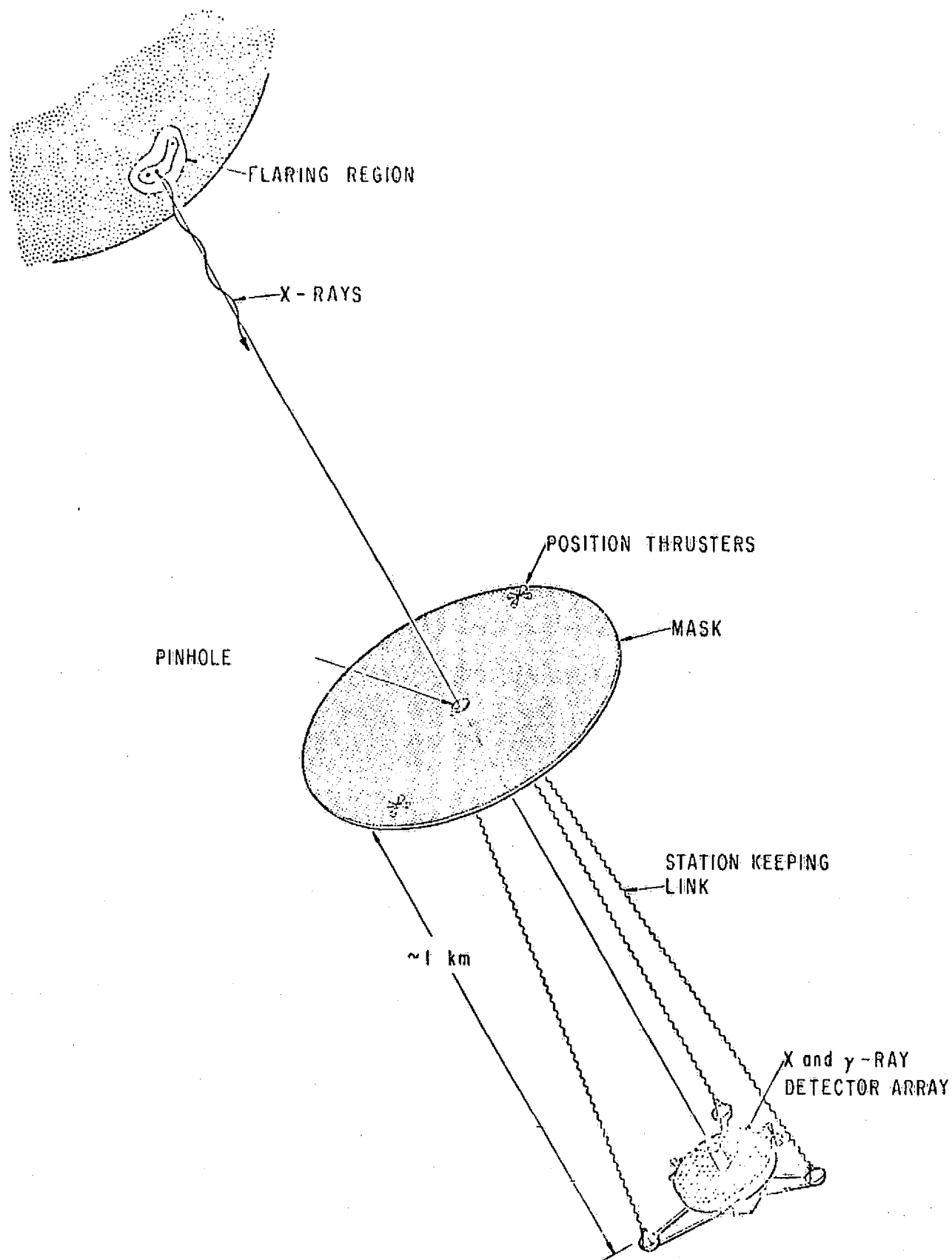


Figure IV-6

APPENDIX - SIMULATIONS

In this appendix, the sensitivity, background and deconvolution considerations discussed in previous sections are illustrated by simulated data for three reference systems.

The spatial distribution of the X-ray source is assumed to resemble the August 7, 1972 white light flare, whose surface brightness has been roughly digitized on a linear scale from 1 to 9 in 1 arc second square pixels as shown in panel a of Figure A-1. The total flux is taken to be that of a "once-a-day" size flare, whose absolute spectrum is illustrated in Figure II-1. A 30 second integration in a 20-30 kev energy channel, along with background and detector window efficiencies used in Figure II-1 are also adopted. The total source counts for the Multielement Collimator Array, Foveal System and Multiple Fan Beam System are therefore 30, 203, and 2440 respectively. The corresponding background count totals (per subcollimator) are 1.1, 7.5, and 5.6. This parameter choice is such that imaging is possible while statistics and background are not negligible.

Panels b, c, and d show the relative counts in the resulting two-dimensional images for the three systems. Because of marginal statistics no background subtraction was attempted for the Multielement Collimator Array (Panel b). Similar results might be expected from the single beam, Multielement Pencil Beam Imaging Collimator and Periodic MECA Systems. Panel c illustrates the image directly obtainable from the Foveal system under the assumption that 40% of its time is spent viewing each of the 2 pairs of emission patches. Background has been included in this simulation, then a (non-optimized) background subtraction algorithm employed to produce the image shown.

Panel e shows the simulated data that would be available from the Multiple Fan Beam System. Starting from this data, the reconstructed image in panel d is obtained

by using a simple Background subtraction/reconstruction algorithm which resembles an Algebraic Reconstruction Technique. Comparable results would be available from the Fan Beam Modulation Collimator.

In no case has any attempt been made to unfold the 4" FWHM resolution which could be attempted in a subsequent step. Alternatively, in each case the data could be regrouped at a coarser resolution level to display itself to better advantage, but at the expense of angular resolution.

It is clear that in the cases illustrated here, the sensitivity advantage of the Fan Beams more than offsets the direct imaging advantage of the other systems.

Although at lower, thermal energies where statistics are not a serious limit, the direct imaging systems would not have been at such a serious disadvantage, the importance of imaging the non-thermal component above 20 kev emphasizes the relevance of the comparison illustrated here.

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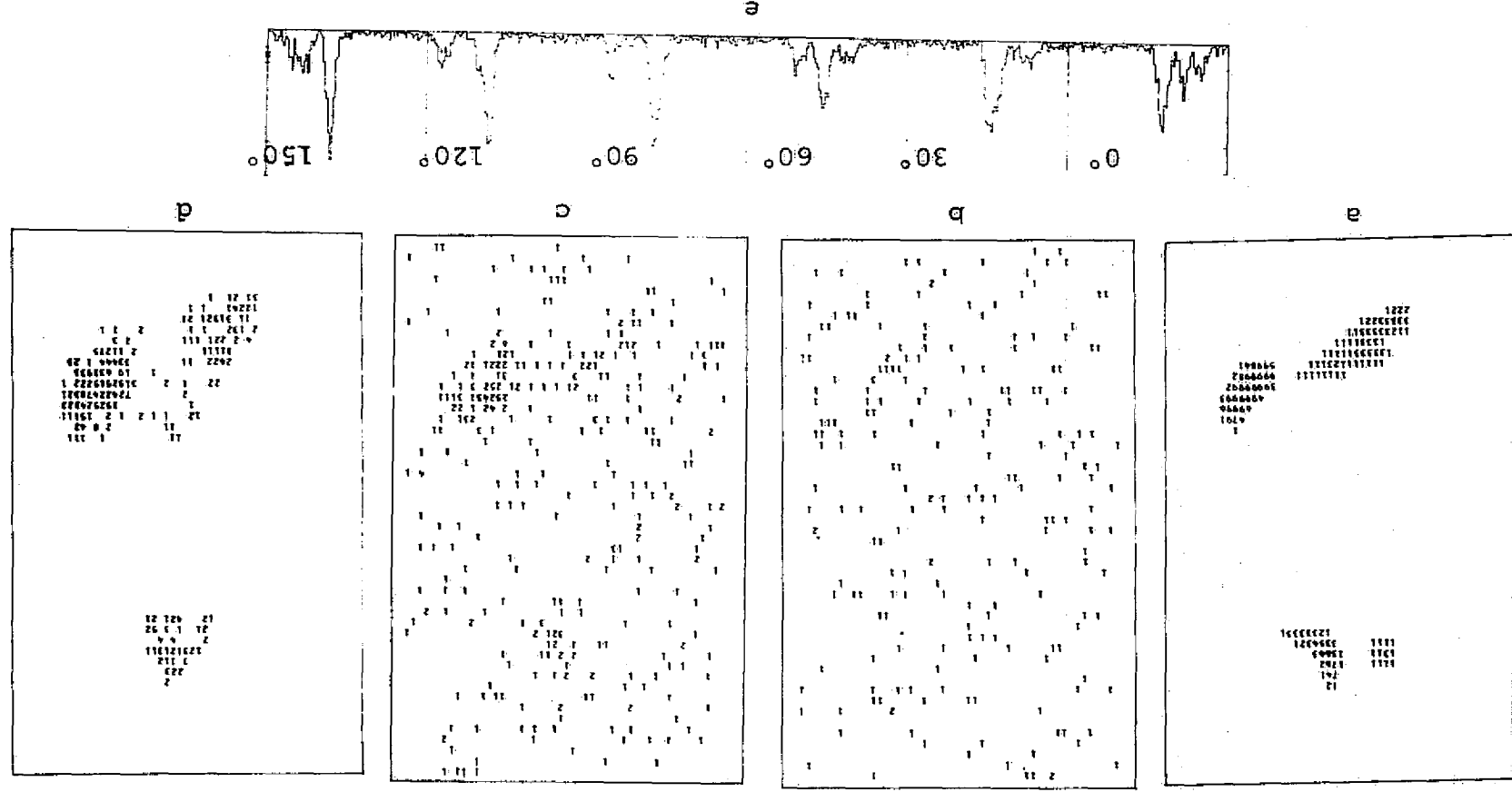


Figure A-1
III-77

SECTION IV

ENGINEERING STUDY

FOR A

HARD X-RAY IMAGING INSTRUMENT

Final Report

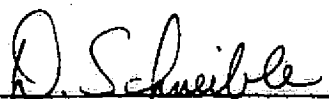
Hard X-Ray Imaging Instrument

Engineering Study

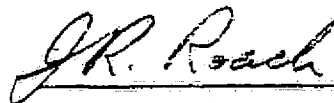
Prepared for

University of California at San Diego

23 July 1976



D. Schneible
Study Leader



J.R. Roach
Shuttle Payloads
Office Manager

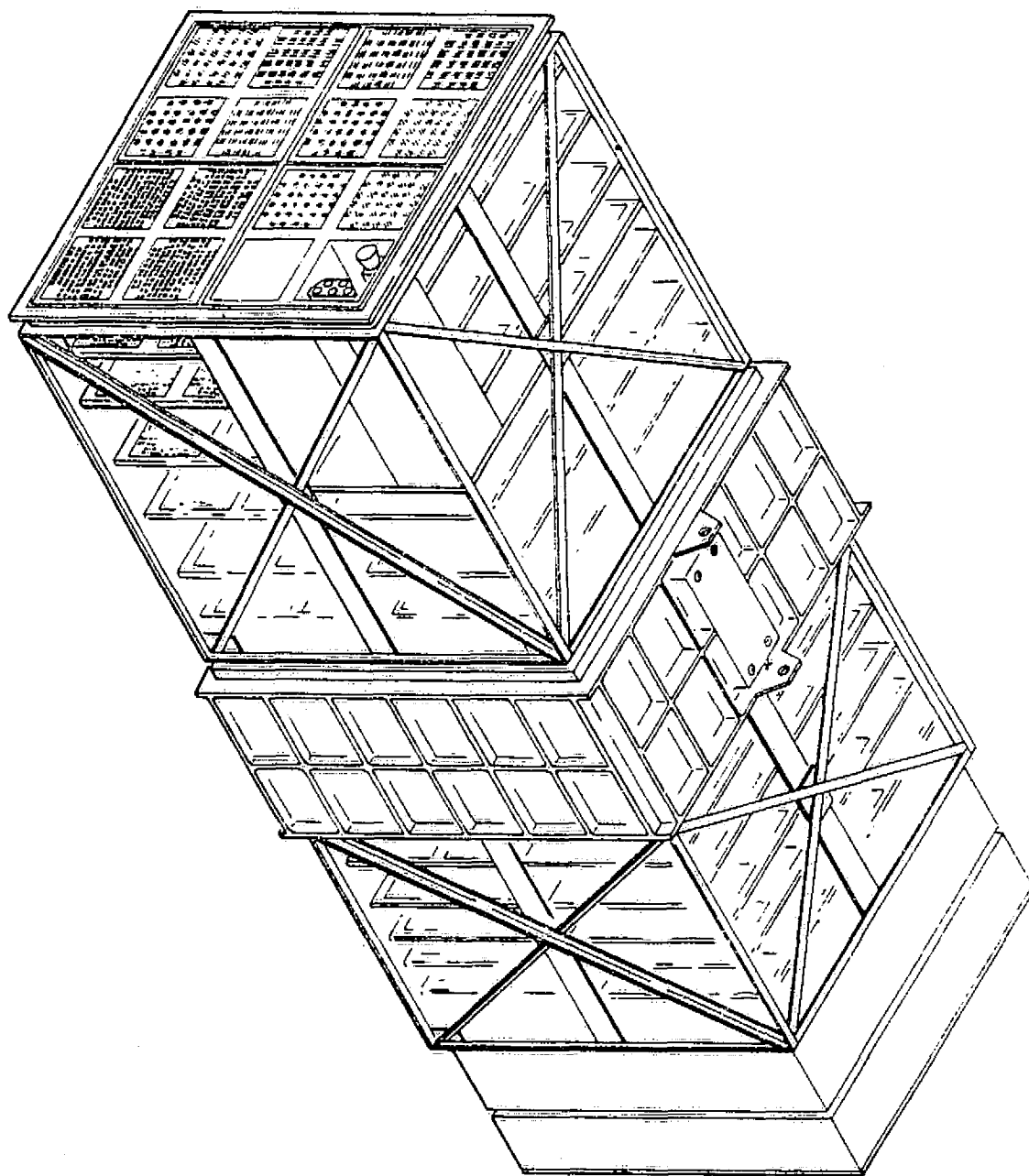
FOREWORD

This is an engineering study for a Hard X-Ray Imaging Instrument to be flown during an early Shuttle/Spacelab mission. This study is the last of a series of three studies performed by and for the Hard X-Ray Imaging Facility Definition Team under the leadership and direction of Dr. Laurence E. Peterson, University of California, San Diego.

The major portion of the engineering study was performed by Ball Brothers Research Corporation under contract to the University of California, but significant contributions to this report were made by several members of the definition team. Those contributing to this effort are acknowledged below.

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HARD X-RAY IMAGING INSTRUMENT



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Appendix

1.0

INTRODUCTION

An engineering trade-off study performed by Ball Brothers Research Corporation (BBRC) for the Hard X-Ray Imaging Facility Definition Team (HXIFDT) was begun on 3 May 1976. The twelve week study was divided into three phases as shown in Figure 1-1, the study schedule. Phase I, the requirements definition phase, was accomplished in 2 1/2 weeks. A kick-off meeting between the HXIFDT and BBRC personnel held during the week of 17 May marked the transition from Phase I to Phase II, the trade-off analysis phase. Due to the large number of trade-off items considered and the relative complexity of the proportional counter trade-off analysis, this phase required approximately one month to complete. The concept design Phase III extended from mid-June through early July with a review of the design concept by the HXIFDT on 30 June. A final briefing of the engineering study was presented at both NASA headquarters and GSFC on 12 July.

1.1

STUDY OBJECTIVES

The study has two main objectives, both of which have been achieved during Phase III of the study. Objective one is to develop a basic configuration of the Hard X-Ray Imaging Instrument (HXII) to an adequate depth to demonstrate its feasibility for shuttle/Spacelab missions. The second objective is to ensure the conceptual HXII is physically and operationally compatible with a variety of balanced or end-pointing schemes which may be deployed on a space shuttle mission.

1.2

STUDY GUIDELINES AND ASSUMPTIONS

This BBRC study was directed by the HXIFDT as part of a series of studies conducted by a number of agencies including the University of California, San Diego (UCSD), California Institute of Technology, (CIT) and others. The results of the HXIFDT science requirements study led to a science trade-off study which in turn led to the BBRC engineering study. Consequently, a number of guidelines

HARD X-RAY IMAGING INSTRUMENT STUDY SCHEDULE

WORK WEEKS | 5/3 | 5/10 | 5/17 | 5/24 | 5/31 | 6/7 | 6/14 | 6/21 | 6/28 | 7/5 | 7/12 | 7/19 |

● DEFINE REQUIREMENTS (PHASE I)

● KICK-OFF MEETING

● TRADE-OFF ANALYSIS (PHASE II)

● CONCEPT DESIGN (PHASE III)

● FINAL REVIEW

Figure 1-1

for the engineering study were generated from the results of the science tradeoff study. A brief summary of these guidelines is given below:

- HXII performance requirements will be defined by the HXIFDT.
- HXII is to interface with various types of pointing systems mounted on a Shuttle/Spacelab; therefore, the physical dimensions should not be greater than approximately 1 m x 1 m x 3 m and the weight should not exceed approximately 500 kg.
- The pointing system used could have the general characteristics of the balanced gimbal system defined in BBRC document F75-06, "Low Cost Small Instrument Pointing System (SIPS) Study," or a variety of other pointing systems not necessarily limited to a balanced system.
- Design concepts will be based on state-of-the-art projected for an initial mission in the 1981 time frame with respect to electronic components and system data processing evolution.
- HXII is to be designed for flexible reuse over a minimum ten year period.
- The study is to determine the feasibility of the HXII and identify areas of technical difficulty that could limit the achievement of the scientific objectives.

As a result of the in-series, and teamwork nature of these studies, the BBRC engineering study isn't a stand-alone feasibility study in the usual sense. The effort involved in defining a feasible concept for the HXII was shared among the agencies involved. Consequently, this report only considers several critical areas that needed "first cut" conceptualization in order to evolve to a final feasible instrument concept. The specific questions addressed in this report are:

- Can the HXII be pointed by a Shuttle pointing system and accomplish scientific goals?
- Can the HXII be assembled and aligned in a lg environment?
- Can two-dimensional proportional counters be developed to meet the scientific requirements?
- Are interface requirements compatible with present NASA concepts for point mount and Spacelab?
- Are the data processing and data reduction requirements compatible with present NASA concepts for Spacelab interfaces?
- Are the mechanical constraints of environments expected by the Spacelab of a level whose severity would restrict the possible accomplishment of the scientific objectives?

The HXII requirements defined in this section are the engineering requirements necessary to meet (1) the science requirements generated during the science trade-off study and (2) the guidelines and assumptions summarized in Section 1.2. Some of these preliminary requirements were modified during the study. The mechanical envelope evolved as a result of incorporation of the scientific apparatus requirements. It takes into consideration the thermal and mechanical constraints in a manner suitable to allow for overall instrument interfacing to a variety of Spacelab fixed or pointing mechanisms either pallet or non-pallet mounting.

Pointing requirements were taken directly from the science trade-off study, but the coalignment requirements were modified by conceptually developing an aspect system which does not require precise instrument internal coalignment.

Power requirements were not given by the science study or covered by the guidelines, but were generated after the conceptual electronics design had been done, primarily by UCSD personnel.

2.1 MECHANICAL REQUIREMENTS AND CONSTRAINTS

2.1.1 Volume

The HXII was not baselined for a particular pointer or geometric applications usage; however, from a systems standpoint and scientific requirements bonds, the volume that appears to provide maximum utilization of viewing area and potential modularity of the design is in the order of 1 m x 1 m x 3.2 meters, without thermal control shrouds. If we consider a nominal 0.1 m for thermal and protective shrouds around the instrument, the maximum volume would be 1.2 m x 1.2 m x 3.4 m.

2.1.2 Weight

Based on an examination of potential structure designs, grid, proportional counters and supporting equipment items, the estimated weight for the HXII is 500 kg.

2.1.3 Viewing Area

From a scientific and technical viewpoint, the baseline requirement for viewing area was for 7392 cm² utilizing 14 collimators.

2.1.4 Balance

The center of gravity appears to be near the geometric center; however, adjustment in the mass can be accomplished to allow for pointer or installation application requirements.

2.1.5 Alignment Requirements

The subcollimator slits for the high resolution fan beams are 50 μ m (0.002-inches) and there are six sets of grids per collimator.

Alignment through the sets of grid (≈ 2.5 meters) should be made to within 5% ($2.5 \mu\text{m} \approx 0.0001$ -inches) at initial alignment and held through launch and orbital operations. This tolerance is an rms figure and refers to each dimension within a subcollimator.

2.1.6 Proportional Counters

Analysis by members of the science team defined the baseline gas requirement as 40 atm-cm for x-ray path length in both counters. This may be obtained by a 20-cm depth at 2 atm of pressure, or an equivalent combination. The gas chambers are to be sealed during operation.

2.2

POINTING REQUIREMENTS

The HXII pointing requirements as defined by the HXIFDT are summarized in Table 2.2-1. These requirements are general enough in nature to be adaptable to a variety of pointing mechanisms.

An aspect system concept which could meet both the solar and stellar pointing requirements of the HXII is presented in Figure 2.2-1. The system would incorporate a fine sun sensor such as those being proposed for the Solar Maximum Mission (SMM) and two star sensors. One of the star sensors would be used for roll information, the second would be used to translate between solar and stellar targets by moving a series of attenuators in and out of the sensor field of view. With the attenuators out of the optical path, the sensor is pointed to a cosmic X-ray source. The position of the source as seen by the instrument determines the alignment between the sensor and the instrument. For solar viewing, the attenuators are moved into the optical path and the sensor pointed to the solar limb. The position of the limb with respect to the solar sensor is then determined, and a value for the misalignment between both sensors and the instrument can be calculated. By using the combination of sensors and instrument readouts, precise coalignment is not required although accurate position readout becomes crucial.

Table 2.2-1

Pointing Accuracy:	3 arc sec (10 arc min roll) on sun
Stability:	0.4 arc sec rms (80 arc sec rms roll) over 10 sec
Motion: Slew	30 arc min/sec point-to-point
Dither	10 arc sec diameter circle, executed repeatedly in 1 sec period

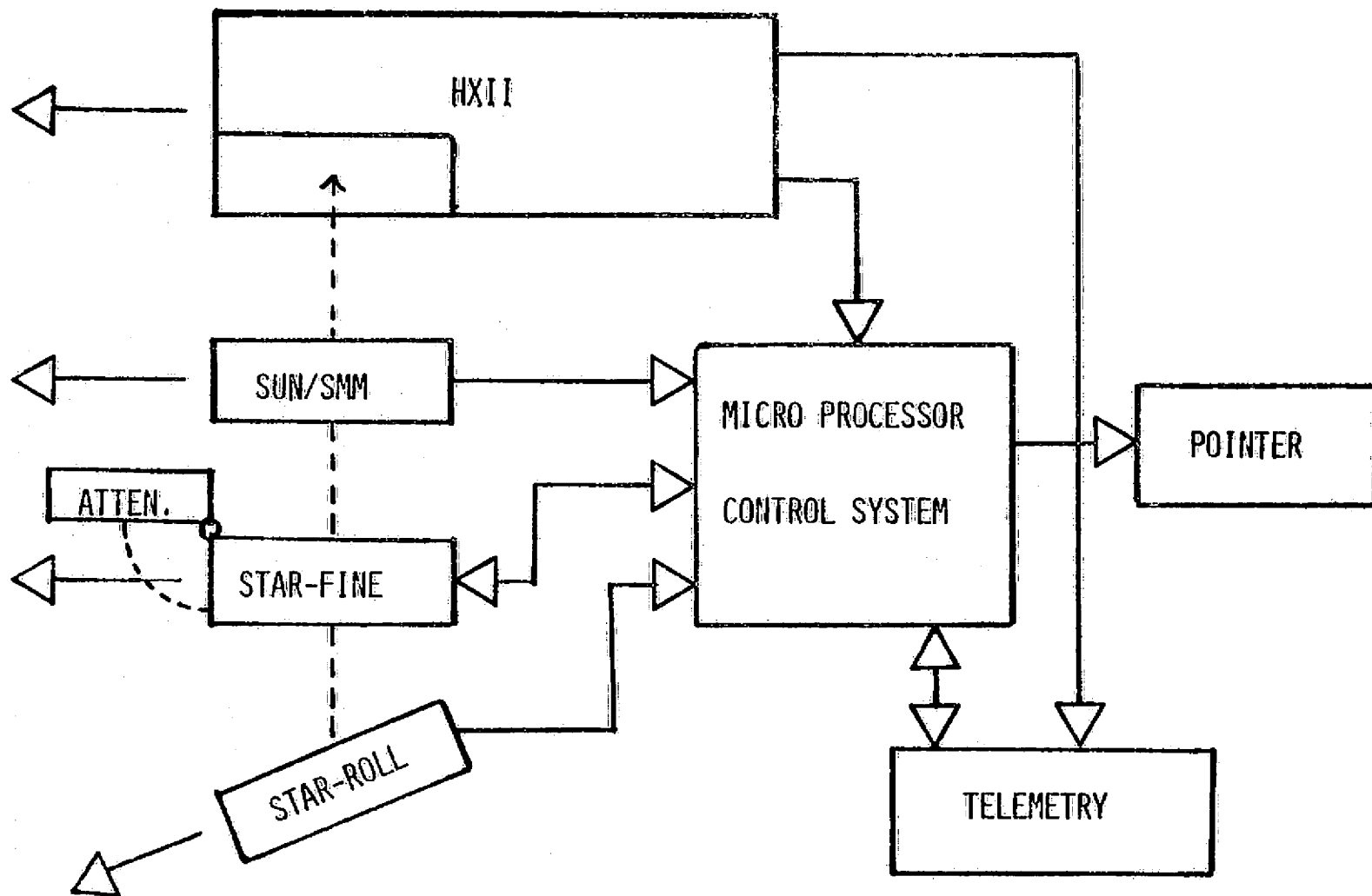


Figure 2.2-1 Aspect System Concept

3.0

TRADE-OFF ANALYSIS

The trade-off analysis conducted during Phase II of the HXII engineering study comprised the major effort of the study. Not only were the necessary trade-offs numerous, but also quite complex, especially the proportional counter configuration trade-offs. In this section all of the trade-offs are discussed. The selected method is then expanded into conceptual design details in Section 4.0.

Section 3.1 deals with the structural trade-offs between two of a variety of possible structural configurations. One consists of four identical structures, each 1/2 meter square. The second is a single structure 1 meter square. Both were modeled mathematically for computer deflection analysis.

The four piece structure follows the reasoning that each quarter size collimator could be aligned vertically and bolted together. However, there is redundant structure inside which reduces active detection area. Presently it is not known how the sections could be fastened together, and to a SIPS gimbal frame, without structural distortion, so it is visualized that alignment will have to be checked after assembly. There is advantage in fabrication of the four section structure since each section is identical.

The single unit structure is an attempt to increase active detection area. A pointer gimbal frame would be a permanent part of both structures. No sheet shear webs were used in either structure since they would have to be removed for alignment access and would cause distortion when replaced afterwards.

Only these two configurations were considered because of the requirement for 7392 cm² viewing area coupled with the 1 x 1 m cross sectional area. The structural design was therefore required

to maintain approximately 75% of the instrument cross section for data acquisition. This proved to be more difficult than anticipated after several unsuccessful attempts. The most promising structural design for maximizing the area for data acquisition was then scaled up to the largest possible option available and an acceptable 6915 cm^2 viewing area obtained. As a result of these requirements and the mechanical constraints they implied, only the structures which provided maximum viewing area and minimum weight could be considered in this engineering trade-off study.

3.1 STRUCTURAL DESIGN

This section describes the approach used for the study for the structural design, the analysis performed, the layouts generated, and conclusions and recommendations regarding the structure. Figure 3.1-1 summarizes the structural design trade-offs used to derive a final configuration.

The baseline configuration was visualized to have a metering structure to support all of the collimator grids. This in turn would be mounted in an integrating structure along with the proportional counters. The integrating structure would mount in a pointing system gimbal frame. A goal of the study was to define the metering and integrating structures.

Early in the study the requirement for 75% of the instrument cross sectional area to be available for data acquisition was identified as a driving constraint (Ref. Section 2.1.3). A layout that was considered a typical structure (combined metering and integrating) which could support the grids and the proportional counters and interface with a pointing control system was generated.

At the suggestion of members of the science team, the first layout was for a quarter module structure; that is, one quadrant of the cross section. It was suggested that grid alignment could be facilitated by aligning one quadrant at a time while being in a vertical position to eliminate bending moments in a gravity field.

After alignment the four quadrants would be secured together and mounted into a pointing system gimbal frame.

Figure 3.1-2 shows the quadrant structure layout and Figure 3.1-3 shows a typical cross section. It is an open truss type structure with the lattice members inside the corner angles to provide a clean exterior for attaching to adjacent sections. The grids are

STRUCTURAL TRADE-OFFS

Options	Advantages	Disadvantages
I. Overall Structure		
1. Separate metering and integrating structure	Mounting at Airy points, align in horizontal position.	Greater weight, reduced viewing area.
2. Single structure including gimbal frame	More viewing area. Utilizes stiffness of gimbal frame. Less weight.	Align in vertical position only.
• Four quadrant structures combined.	Stiffer in horizontal position. Better access for alignment. Modular.	Reduced viewing area due to redundant structure.
• Single integral structure	Maximum viewing area. Lowest weight. Access adequate.	Less isolation of collimator from environment.
II. Structural Configuration		
1. Open truss design	Maximizes accessibility to 82 internal grids. Lowest weight. Adaptable to various thermal control methods.	Low modulus and torsional resonant compatibility with pointing systems.
2. Shear web		
III. Materials		
1. Aluminum structure	Readily available. Easy to modify. Moderate cost.	Low modulus of elasticity. Difficult thermal control problems.
2. Graphite/epoxy structure	High modulus. Low weight. Good thermal control features.	Higher initial cost for engineering and manufacturing tooling over aluminum type structures.
3. Beryllium	High modulus. Low weight. Moderate thermal control features.	High initial cost and technical design considerations.
4. Invar/fermico alloys	Thermal stability and higher bulk modulus features.	Fabrication and thermal control coupled with high mass density properties.

Figure 3.1-1

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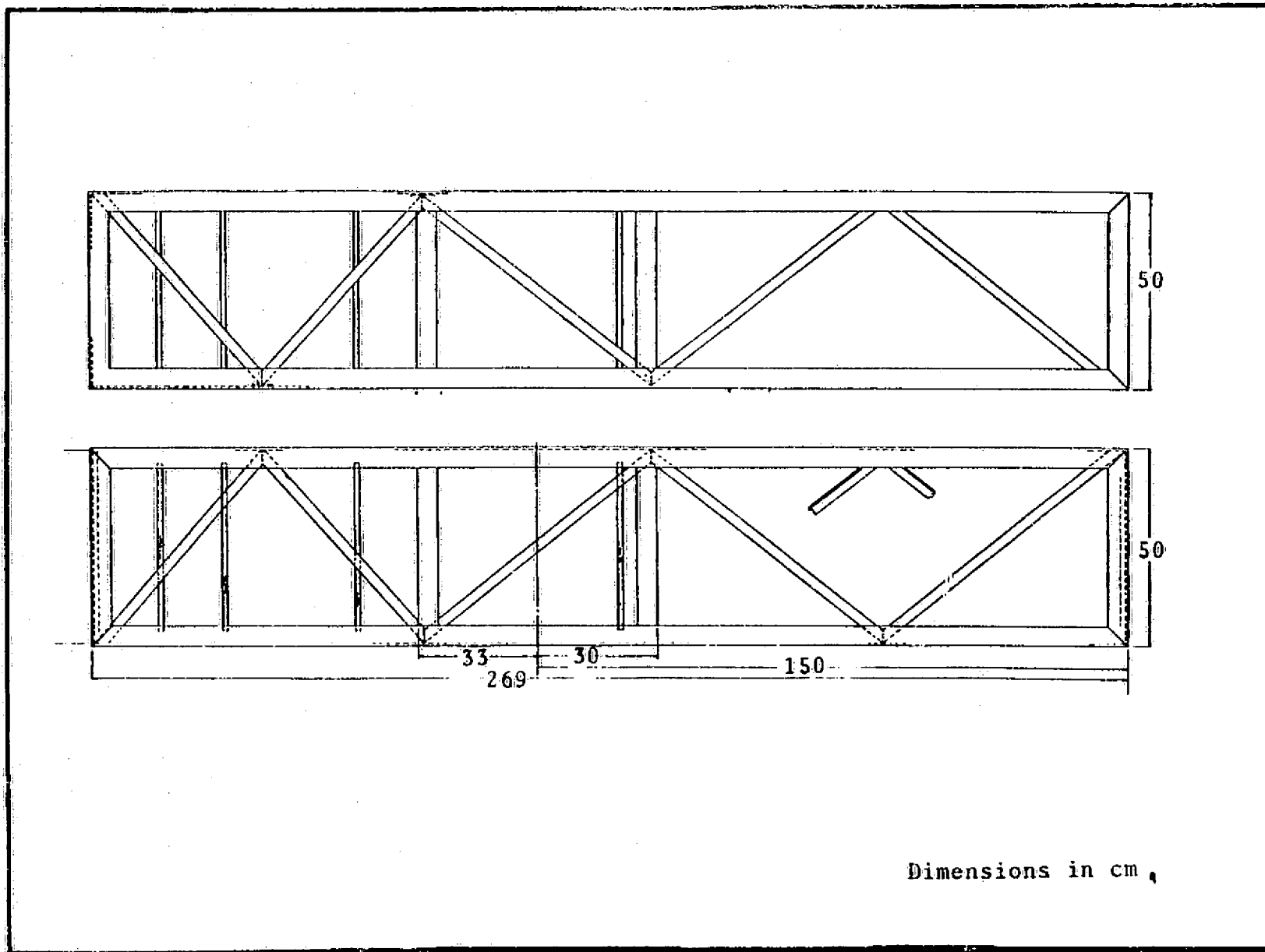


Figure 3.1-2 Single Quadrant Structure L. V.

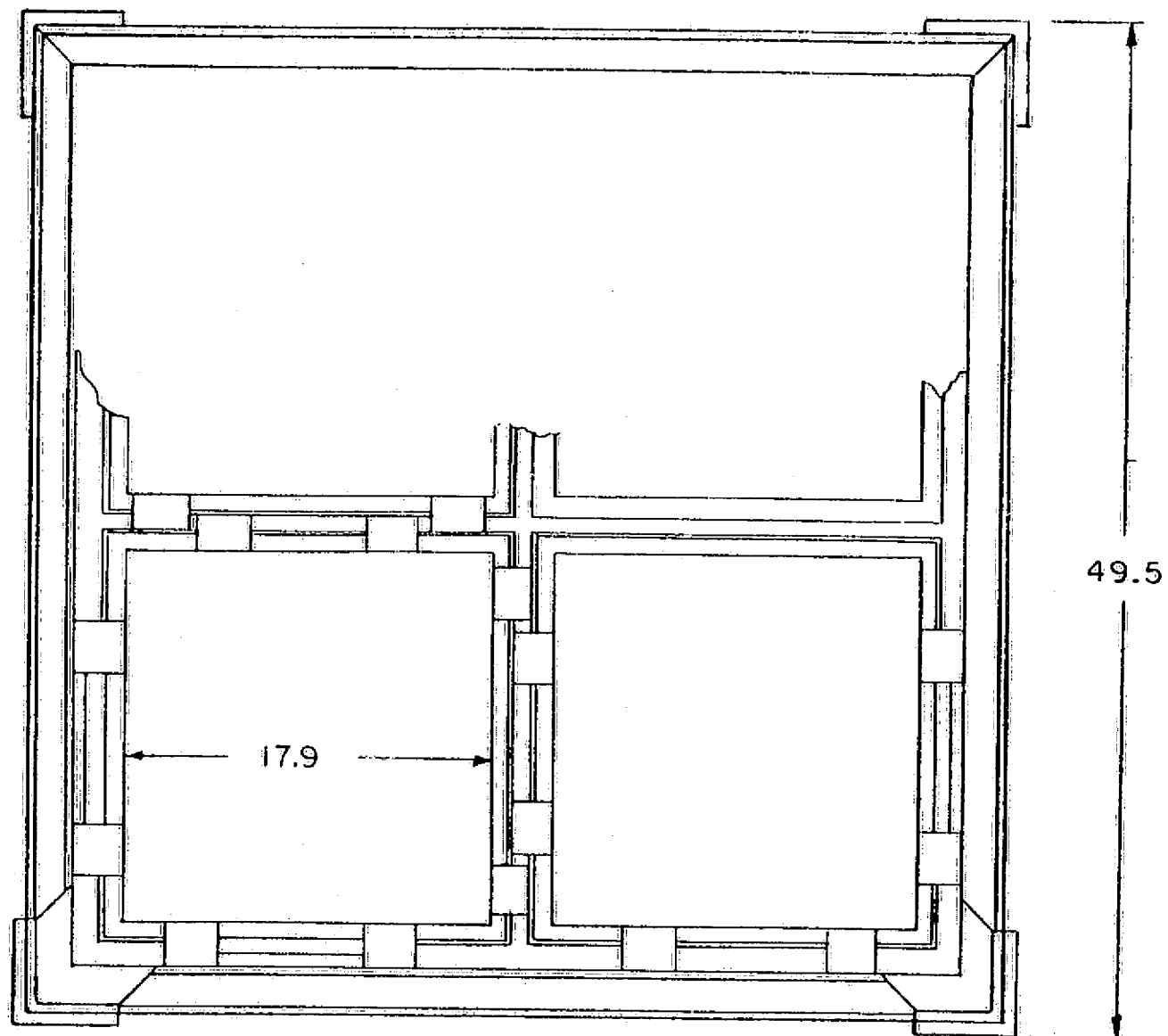


Figure 3.1-3 Typical Section - 1/4 Meter Structure

mounted in frames with adjustment provisions. Shear webs were not used (in this or subsequent layouts) to minimize weight and maximize access to adjust the grids. Grid frames were placed at nominal fractional positions; that is, at $L/2$, $L/4$, $L/8$, where L is the distance from front to back grids.

This arrangement accommodates 16 square collimator spaces, whereas the baseline configuration has required 14. The two extra spaces were subsequently designated for a whole-sun monitor and an aspect system.

From the layout it was determined that the useful open area was 52.2%. However, only 4488 cm² was available for the 14 collimators.

Another layout was generated for a single, unitized structure. This provided 60% open area, but still only 5162 cm² for the 14 collimators. When this was reported to the science team the decision was made to relax the approximately 1 m x 1 m cross section requirement to 1.14 m x 1.14 m.

A final layout was made for the 1.14 m size, along with a proportional counter. The proportional counters were coordinated with the grid frames to determine useful open area, and it was found that 6915 cm² was available for the 14 collimators. This appeared acceptable. The layout is shown in Figure 4-1 in Section 4.0. No layout was ever made for separate metering and integrating structures since they would obviously reduce viewing area.

It was concluded that the HXII could have a dedicated gimbal frame as a permanent part of the structure. The load paths are from the gimbal shafts through the gimbal frame, then through the structure to the grids and the proportional counters. Merely attaching the gimbal frame to the structure would most likely distort the structure by more than 2.5 μ m and adversely affect grid alignment. It can be considerably stiffer than the structure and that stiffness should be utilized as part of the structure.

3.1.1 Math Models

A 20 node finite element model was made for the one quadrant structure. This model is shown in Figure 3.1-4, and the analysis results given in the Appendix. When mounted in the horizontal position at the gimbal frame support points (planes at 5, 6, 7, 8, 11, 12, 13, and 14), deflections at the front were on the order of 2.5 μm and at the back, 25 μm . Larger size structural elements were inserted in the model with negligible effect.

Later it was realized that the model was in error because the loads included an 18 kg proportional counter at the rear. In reality, the proportional counters would not be added until the four quadrant sections were assembled into a single structure. So it appears that the quadrant concept is a viable candidate and feasibly could be aligned in a horizontal position. The trade-off here is how to mechanically design the modules without significant loss in the amount of aperture area. This should be considered in further analysis before concluding that the modular design approach cannot be used. The modularity feature could produce benefits in the technical development areas and provide a ready method for upgrading the HXII instrument without total instrument modification, but at the quadrant level.

A 54 node model was constructed for the single unitized structure, based on a .99 m square section and again with the grids located mostly behind the center grid. The model is shown in Figure 3.1-5 and the results are given in the Appendix. The deflections were all less than 25 μm in the horizontal position except the rear mid-plane, nodes 7, 50, and 31. These were on the order of 38 μm . This could be corrected with a bulkhead utilizing the area not open to X-rays. A similar bulkhead is necessary at the front to eliminate twisting, but was not included in the math models.

Additional modeling of the 1.14 m structure should be performed with the grids at the position finally selected.

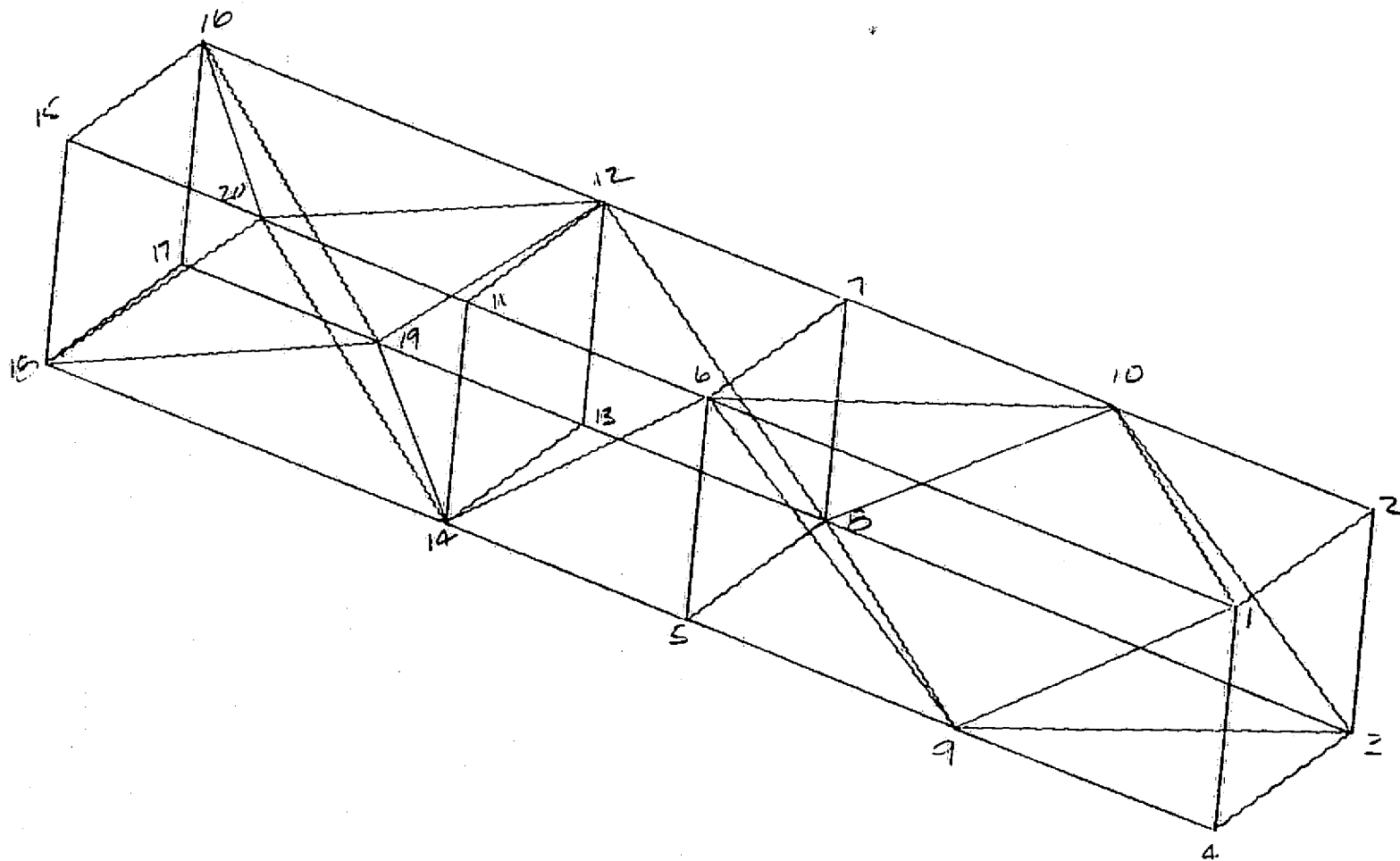


Figure 3.1-4 · 20 Node Math Model - 1/4 Structure

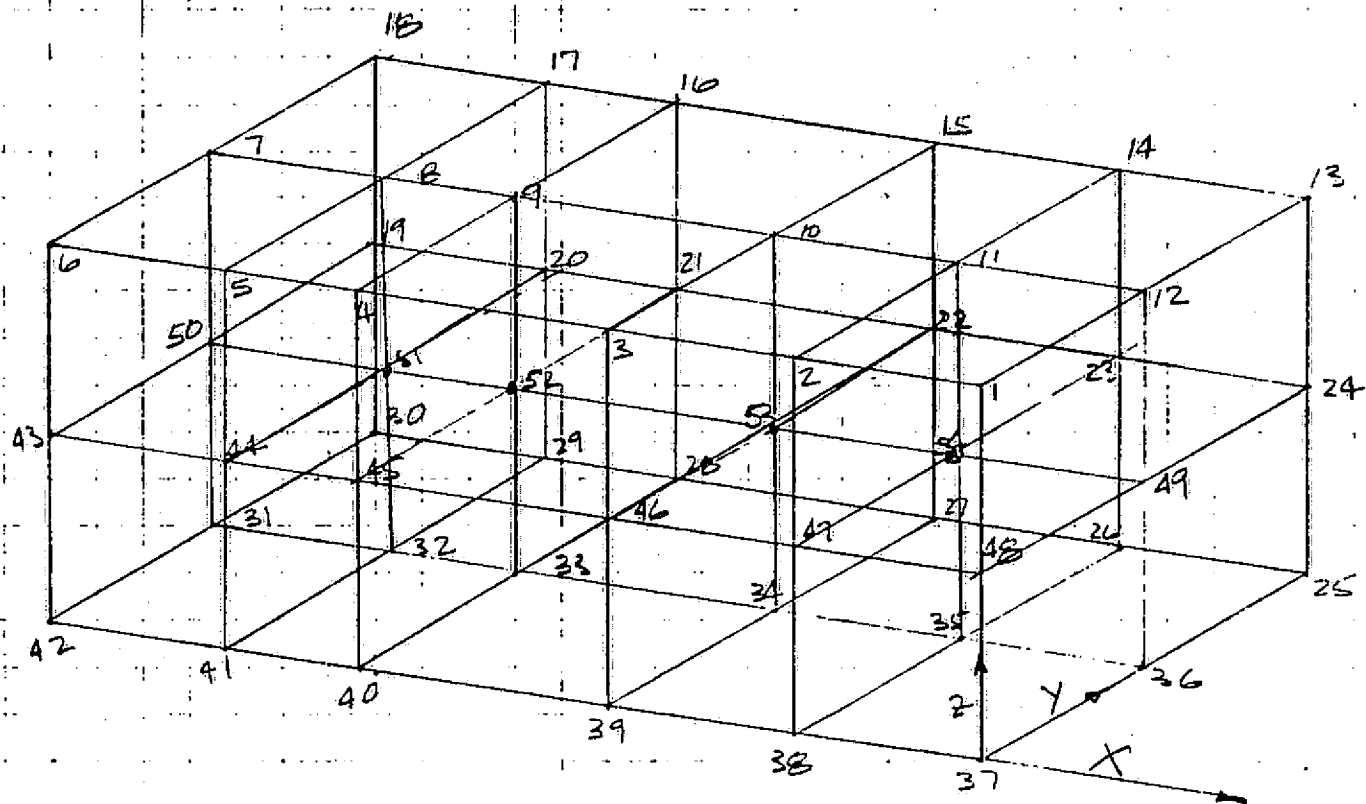


Figure 3.1-5 54 Node Math Model Full Size Structure

Principally, aluminum was considered for the structure due to its reasonable cost and ready availability. Since this instrument is to have a ten-year service life, it is visualized that many alterations will be performed. A subsequent study must be performed to trade off alternate materials and manufacturing methods along with potential geometric configurations that may lend themselves to a more cost effective method achieving the scientific objectives.

3.1.2 Other Structural Approaches

It was pointed out by science team members that structures mounted at the Airy points have been used successfully for finely aligned collimators. The Airy points are the minimum deflection points of an overhung beam on two supports. Figure 3.1-6 shows a sketch of this concept. Since the proportional counters need not be accurately aligned to the collimators, they can be independently mounted.

This concept requires two structures and the open area will be reduced. If a reduction of area is eventually acceptable, this concept should be fully evaluated.

These alternate approaches are based upon an optical bench concept for the design which may or may not allow horizontal 1 "g" alignment and testing. Stiffness and thermal distortion modeling will be necessary to verify the feasibility of alternate geometric, structural and packaged configurations.

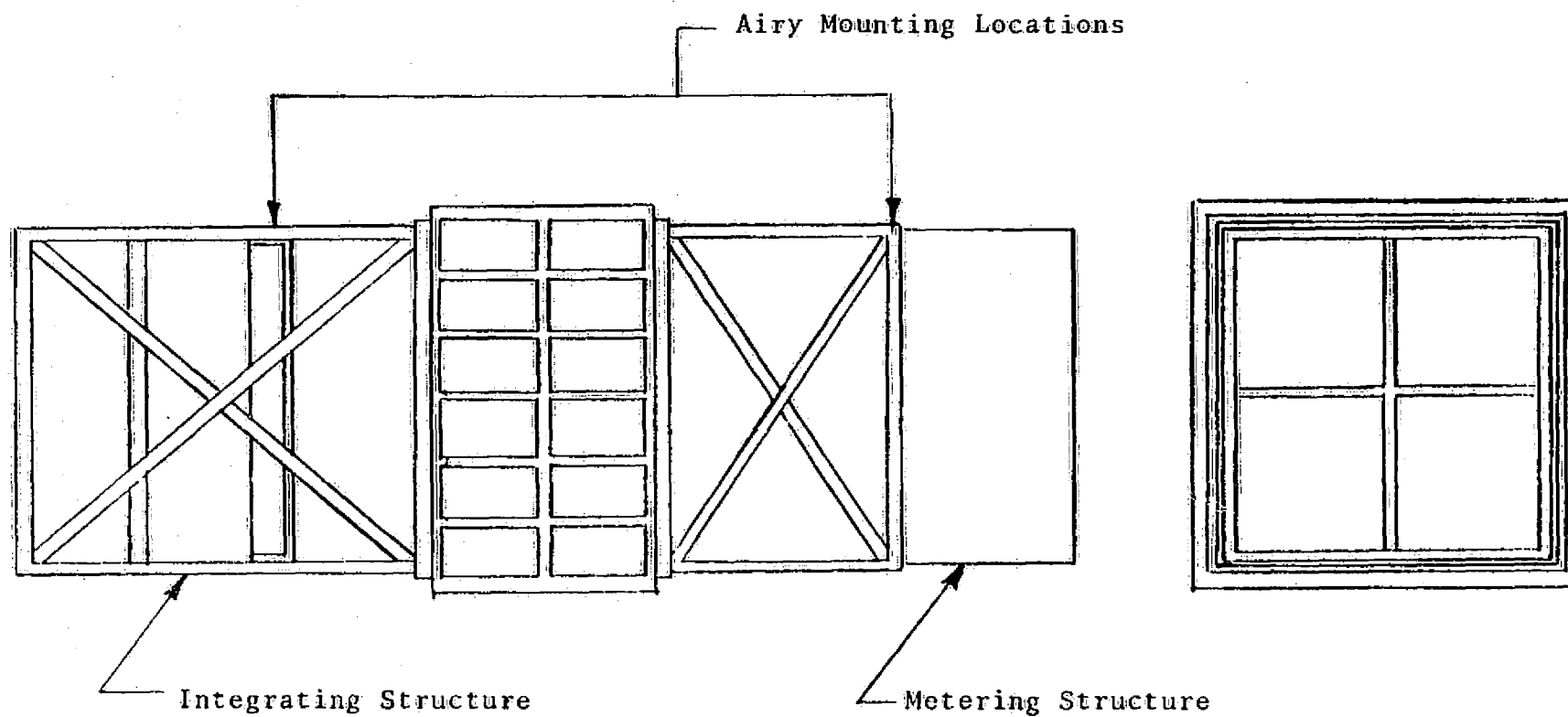


Figure 3.1-6 Airy Mounting

3.2 PROPORTIONAL COUNTER CONFIGURATION

Selection of the method of spatial readout for the Hard X-Ray Imaging Instrument proportional counters involves a large number of considerations on the system and subsystem level. In the following we present the essential elements of the selection process as it has been applied to the detector system. First we present the various readout methods which might conceivably be contemplated. This is followed by the application of broad criteria or considerations which eliminates several candidates. The remaining options are then subjected to a more detailed analysis including such criteria as mechanical and electrical complexity, flexibility to incorporate additional features, interchangeability, etc., with the objective of maximizing performance of the detectors.

The subjects discussed in this section may be summarized as follows:

- A detailed tradeoff of several position readout schemes
- A recommendation which allows the most promising schemes to be implemented without changing the proportional counter construction or layout
- Information necessary for a detailed tradeoff of the electronics to identify the best compromise from a cost-performance standpoint
- A recommended proportional counter mechanical configuration

3.2.1 Readout Methods

Four categories of spatially detecting the location of interacting photons or charged particles in a proportional counter have been identified. These are: (1) delay line readout; (2) direct anode or cathode readout; (3) resistive wire readout; and (4) other methods, which are combinations of these and/or include other features. Each of these categories is subdivided into several groups as discussed below.

3.2.1.1 Delay Line Readout

The first applications of delay lines for detecting the location of events interacting in proportional counters made use of an external delay line (Grove et al, 1972). The sense wires were connected to an etched copper strip which was capacitively coupled to an external delay line with rectangular cross section. Timing pulses obtained from both ends of the delay line start and stop a time-to-height converter, the output of which thus provides a measure of the location of the avalanche in the proportional counter.

An extension of this technique is to directly connect the sense wires to the delay line thus increasing coupling efficiency and signal-to-noise in the position sensing.

In essentially simultaneous, but independent developments, Los Alamos Scientific Laboratory (Lee et al, 1972, Flynn et al, 1973) and Ball Brothers Research Corporation (Gilland and Emming, 1972, Emming and Gilland, 1973) devised a proportional counter in which the cathodes around the anode plane are wound as a continuous coil, thus forming a helical delay line. Advantages of this scheme over the external delay line include 100% coupling efficiency and elimination of most feedthrus. The latter is of significant importance in systems with large numbers of wires.

Two dimensional readout systems have been built using both the external and integral delay line schemes, and both have been perfected to the point that spatial resolution is essentially limited by the physics of electrons in gases.

3.2.1.2 Direct Readout of Anode or Cathode

This is the oldest method of gaining positional information. Individual anode wires, or groups of anode wires, are provided with separate amplifier chains, thus identifying in one direction the location of the event. The other coordinate, along the anode wires, can be obtained by cathode wires which run perpendicular to the anodes. The induced pulse on the cathode wire is completely time-correlated with the anode pulse, but of opposite polarity.

For completeness, it should be mentioned that the coordinate perpendicular to the anodes can also be obtained by a cathode plane whose wires are parallel with the anode wires. This provides flexibility of using the information available (pulse height, pulse position, pulse shape) in various ways, which may be advantageous for optimizing the use of electronics.

3.2.1.3 Resistive Wire Readout

Resistive anodes or cathodes can be used for position determination. There are two basic methods: charge division and rise time sensing. The resistive electrode forms a diffusive RC line by its distributed resistance and capacitance with respect to adjacent electrodes. In the charge division method the amount of charge collected by charge sensitive amplifiers at one end of the line is compared with the total charge consisting of the sum of the charges at both ends of the line. The ratio of the two is a measure of the position of the center of charge of the interacting event in the counter.

In the rise time method, circuits are used which sense the difference in rise time of pulses arriving at the end of the line and which generate timing pulses whose time difference is closely proportional to the position. The electronics for this scheme is almost identical to the electronics for the delay line readout method. Borkowski and Kopp (1970, 1975) have perfected the rise time method whereas Alberi and Radeka (1976) describe applications of the charge division method.

An excellent treatment of the optimum signal processing for both methods as well as for the delay line readout scheme is provided by Radeka (1974).

3.2.1.4 Other Readout Methods

In this category we include schemes such as the drift chamber and the center-of-charge readout which, however, use individual wires read out in the conventional way. The drift chamber works only for charged particles, since a reference timing signal is required to establish the passage of a particle through the chamber. The deposited charge is drifted towards an anode wire and the arrival time of the pulse thus establishes position.

The center of charge method utilizes the induced pulses on several adjacent wires. An on-line computer determines the center of gravity of the charge deposited in the chamber to an extremely high precision (tens of microns). These two methods have been developed at CERN by Charpak et al. (1973) and Breskin et al. (1974, 1975) for the drift chamber and by Jeavons et al. (1976) for the center-of-charge technique.

Combinations of techniques discussed in Sections 3.2.1.1, 3.2.1.2 and 3.2.1.3 can be devised. Some examples will be mentioned in the next section.

3.2.2 Candidate Readout Methods Considered

In this section we outline several possible implementations for the Hard X-Ray Facility based on the readout methods discussed above: delay line readout, direct readout and resistive wire readout.

3.2.2.1 Delay Line Readout Schemes

One-Dimensional Delay Line Readout

In this case the 32 spatial elements are long, wide strips, all running perpendicular to the anode wires. A delay line is wrapped around the anode plane. Readout can be performed using both ends of the line only, or by adding taps on the line to increase count rate capability.

Schematically this method is shown in Figure 3.2-1. In this figure and all following figures in this section, the anodes run in the

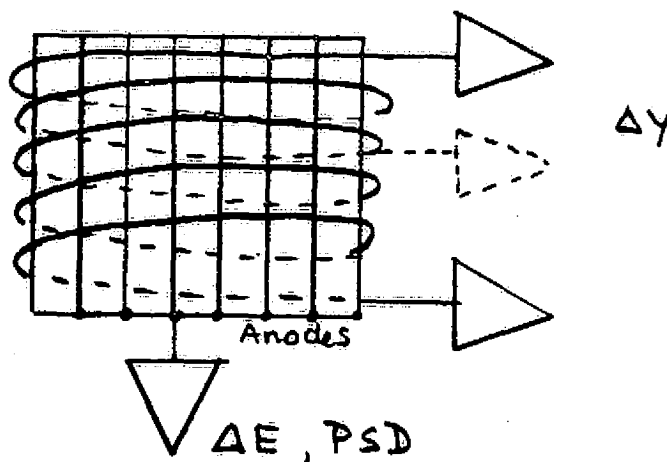


Figure 3.2-1 Single Delay Line Readout

vertical direction (Y-direction). The delay line thus provides position information, ΔY , whereas the anode plane is used for energy information, ΔE . In addition pulse shape information is available from the anode to discriminate against charged particles.

This pulse shape discrimination (PSD) is based on the fact that penetrating charged particles leave an extended ionization track in the chamber which produces a slower pulse than X-ray events, where the primary photoelectron stays close to the location of interaction.

One-Dimensional Delay Line Readout-Combined with Direct Anode Readout

In this case the delay line is laid out in the same manner as in the previous section. The difference is in the arrangement of the anode wire readout. Instead of a single anode readout, the anodes are connected in groups, and each group is read out by a separate amplifier chain. Figure 3.2-2 indicates the scheme.

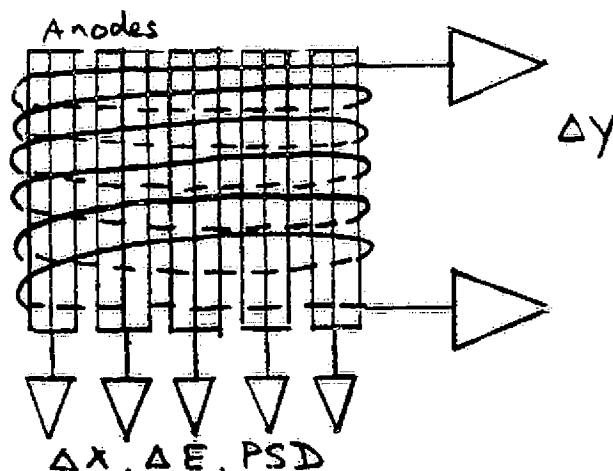


Figure 3.2-2 Single Delay Line Readout Combined with Direct Anode Readout

Two-Dimensional Delay Line Readout

The two spatial coordinates can be obtained by using two delay lines wound in perpendicular directions to each other on different sides of the anode plane (see Figure 3.2-3). This arrangement uses the minimum amount of electronics.

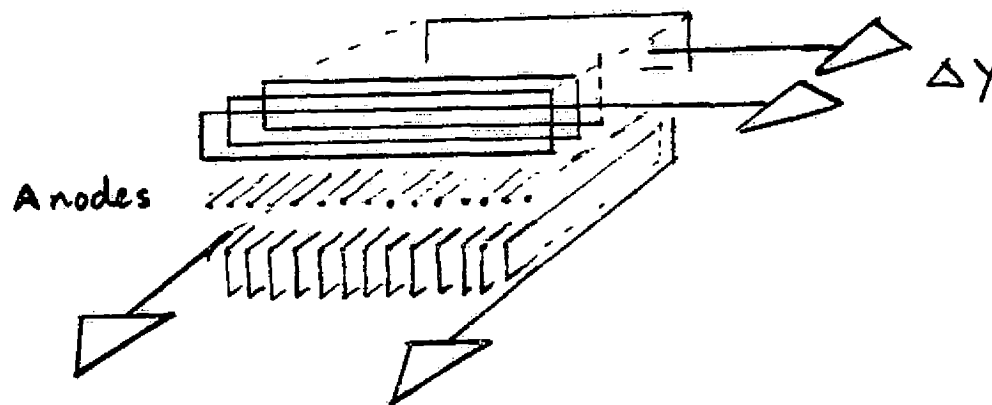


Figure 3.2-3 Two-Dimensional Delay Line Readout

3.2.2.2 Direct Readout

Direct Anode Readout Combined with Direct Cathode Readout

Here the anode wires are connected into m different groups, while one cathode plane is connected into n wire groups. This arrangement results in $m + n$ amplifier chains for position readout, where $m \times n \geq 32$. See Figure 3.2-4.

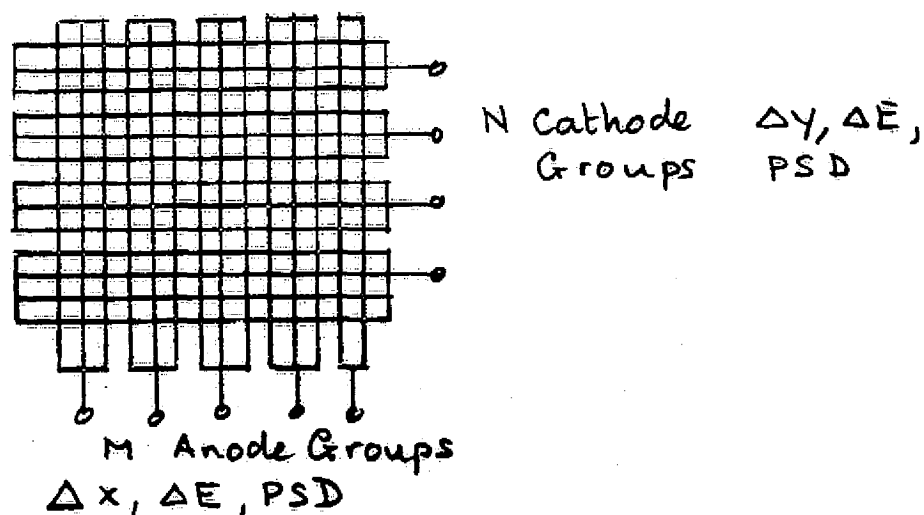


Figure 3.2-4 Direct Anode and Cathode Readout

Energy and PSD information can be obtained from the anodes or from either of the cathode planes.

Direct Cathode Readout

This scheme is very similar to the one above, except that the two cathode planes are used for obtaining position information in an arrangement of $m \times n$.

Both methods mentioned here are hardware intensive, in that the number of amplifiers is substantially above the minimum required in the two-dimensional delay line readout method.

3.2.2.3 RC-Line Readout

The variations that can be considered with resistive wire readout are very similar to those using delay line readout as discussed in Section 3.2.2.1. Instead of a delay line wrapped around or close to the anode plane, the readout can be performed by connecting resistive wires in a zigzag fashion. The resistive wires can be either the anodes themselves, or one or both cathode wire planes. The first three schemes closely resemble the schemes enumerated in Section 3.2.2.1 whereas the fourth through sixth method are other variations on the same theme.

One Dimensional RC Cathode Readout

All anode wires are connected. One cathode wound in zigzag fashion provides the position information. See Figure 3.2-5.

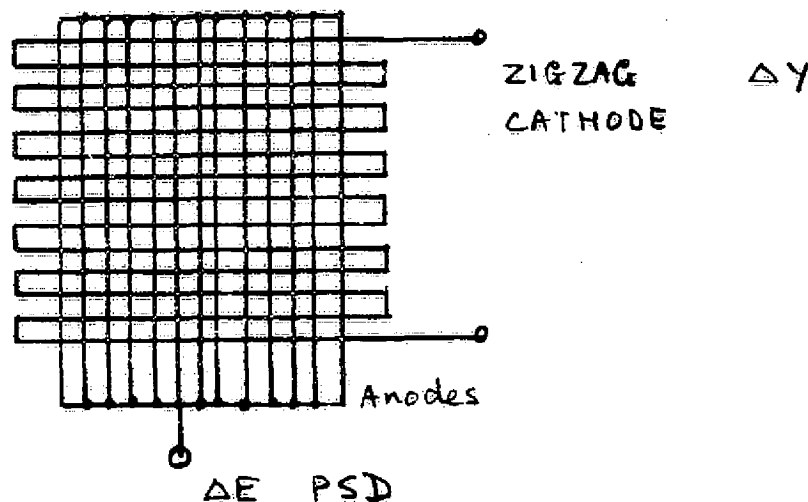


Figure 3.2-5 One-Dimensional RC-Line Readout Using a Cathode

One-Dimensional RC Cathode Readout Combined with Direct Anode Readout

One zigzag cathode provides ΔY . A number of anode groups provides ΔX , ΔE and PSD. See Figure 3.2-6.

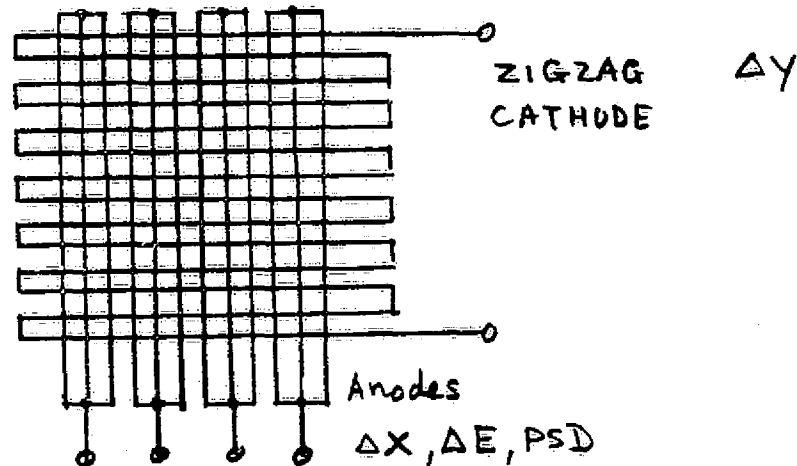


Figure 3.2-6 RC-Cathode Combined with Direct Anode Readout

Two-Dimensional RC Cathode Readout

Two zigzag cathodes are used for the two spatial coordinates whereas the anode yields energy and PSD information.

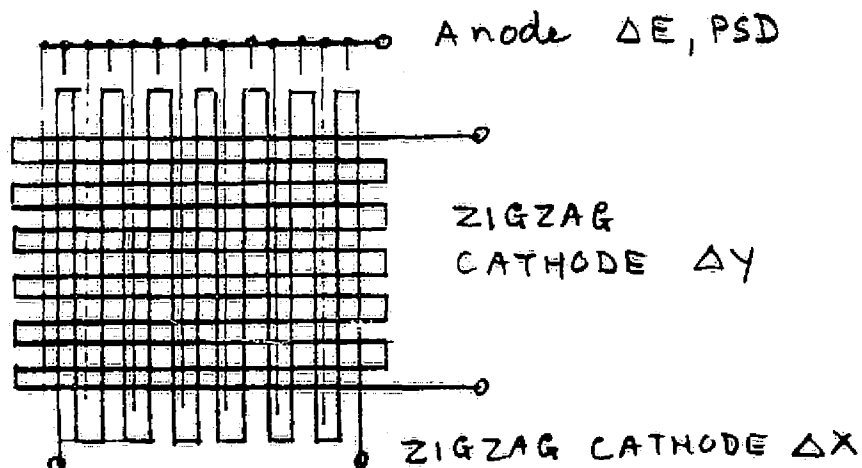


Figure 3.2-7 Two-Dimensional RC-Cathode Readout

One-Dimensional RC Anode Readout Combined With Direct Cathode Readout

This scheme is complementary to the one mentioned under 3.3.2. See Figure 3.2-8.

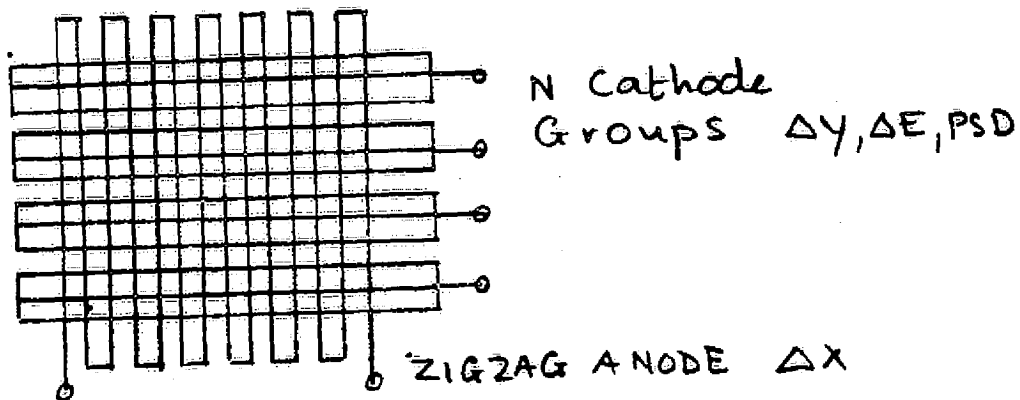


Figure 3.2-8 One-Dimensional RC-Anode Combined with Direct Cathode Readout

Two-Dimensional Resistive Anode Readout

The ends of the anodes are connected to each other by resistors. Combining the outputs at the four corners yields the two dimensional information:

$$(A + B) - (C + D) \rightarrow \Delta Y$$

$$(A + C) - (B + D) \rightarrow \Delta X.$$

See Figure 3.2-9.

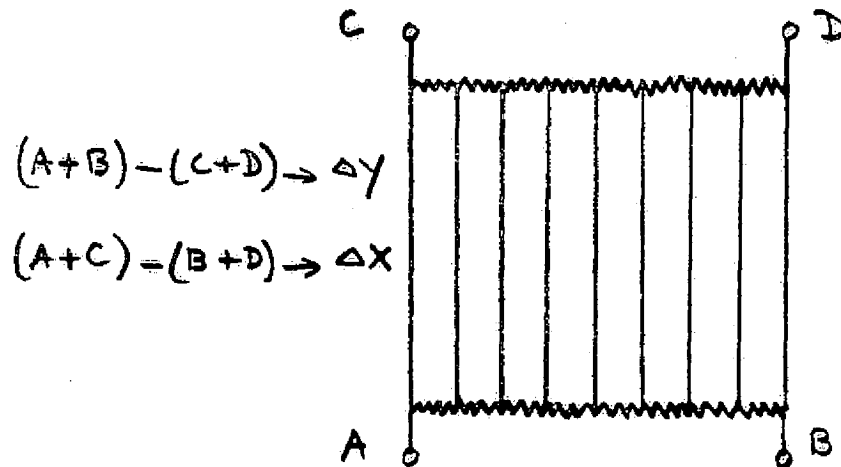


Figure 3.2-9 Two-Dimensional Resistive Anode Readout

Combined Delay Line - RC Anode Readout

Here the zigzag anode is surrounded by a delay line to generate the two-dimensional information. See Figure 3.2-10.

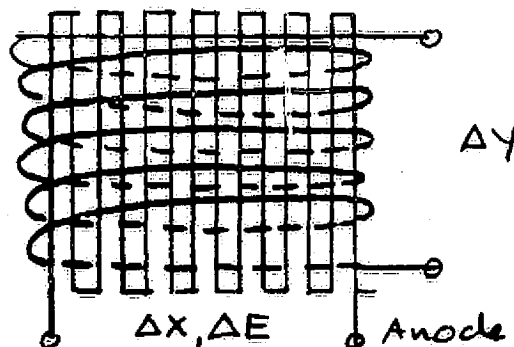


Figure 3.2-10 Combined Delay Line RC-Anode Readout

3.2.3 Tradeoff Criteria

The several spatial readout methods enumerated in Section 3 must be compared in the light of the specific requirements imposed by the Hard X-Ray Facility. In this section we discuss these requirements in some detail.

3.2.3.1 Compatibility of Readout Scheme with Subcollimator Aspect Ratio

For the periodic elements, in particular the high-resolution fan beams, the overall field of view is determined by the subcollimator boundaries ("walls"). To maintain a reasonably uniform sensitivity over the various periodic beams, particularly when the whole system is offset from the sun center, it is highly desirable that the length to width ratio of a subcollimator stay close to 1. This requirement essentially rules out all one-dimensional readout schemes, since these generate long slender subcollimators which are not very suitable for viewing the sun with the fan beams in several orientations.

3.2.3.2 Complexity of Readout Method

Of the three basic readout schemes, the ones using direct anode or cathode readout are the least difficult to design, fabricate and test. Next are the resistive anode or cathode methods followed by the delay line technique. Delay lines require careful optimization of the electrical parameters, as well as physical layout of wire spacings. Dispersion, the variation of propagation velocity with frequency, must be minimized, requiring phase compensation of the delay line, which is largely an experimental procedure. Thus, in delay line readout the design of the proportional counter is tied to the design of the delay line, leaving less flexibility than in the other two categories.

3.2.3.3 Spatial Resolution Capabilities of Readout Schemes

Both the delay line and resistive wire readout methods offer the potential of high spatial resolution in the direction along the anode wires and combine this capability with a minimum of electronics. This feature results from the fact that the induced pulse on the cathode plane has an envelope whose peak location (or equivalently: whose center of charge) is indicative of the position of the proportional counter avalanche. Since this peak does not have to coincide with the position of a particular cathode wire, it is possible to interpolate between cathode wires if electronically the peak can be determined accurately enough. It has been found that the electronic resolution can be less than 0.1 mm FWHM along the anode wire, so that ultimate spatial resolution is set by other effects involving electron-gas physics.

However, it must be noted that in the direction perpendicular to the anode wires the spatial resolution is basically set by the anode wire spacing. This is so because X-ray events interacting in the chamber, mostly produce only a single avalanche on one anode wire.

For the present application the spatial resolution requirements are moderate, however, at least with the multigrid collimators. Resolution becomes only important in the boundary regions between subcollimator cells where a zone of confusion exists as to which collimator produces a detected event. These boundary problems can be minimized by allowing some dead zones to exist between collimators. If, however, one were to use coded apertures for imaging purposes then the resolution requirements over the whole counter area become a significant design criterion. Realistically only the resistive wire or delay line readout methods would be suitable in such a case, the direct readout schemes requiring too much electronic processing circuitry. The same would be true for the foveal element.

if the total number of foveal elements would be increased significantly, such as would result from an increased field of view from 32 arc sec to 128 arc sec, generating 1024 elements.

3.2.3.4 Crosstalk Between Spatial Elements

There are several sources for coupling effects between spatial elements in the proportional counter. An obvious one occurs when an event interacts close to the boundary between elements, produces a photoelectron which penetrates into a neighboring element, or when a fluorescent photon (escape photon) or compton electron is generated. These are problems having little to do with the particular readout method adopted. They must be taken care of in the electronics (anticoincidence, pulse shape discrimination, see Section 3.2.3.9) and by the physical layout of subcollimators. Another source of crosstalk in spatial readout systems is electrical cross-coupling which can occur in delay line and RC-line readout schemes. As a rule it is wise to isolate the two electrical wave functions (X and Y) propagating along the lines by an intermediate plane such as the anode plane. Some schemes are more susceptible to this effect than others and will therefore have a lower rating.

3.2.3.5 Ease of Implementing Drift Fields

The total amount of stopping power required in the two proportional counters dictates the use of drift fields outside the proportional region of the counter. This results from the fact that proportional counters cannot be made arbitrarily thick without the use of excessively high voltages to provide the multiplication fields. It is therefore customary to include a separate drift region, using another electrode, which now provides the required gas thickness. X-ray events interacting in this drift region see a constant electric field which

drives them towards and into the proportional counter region where they are accelerated towards the anode and experience multiplication through secondary ionization.

In some readout schemes this requirement of a drift field interferes with other requirements. This is especially the case with two-dimensional delay line readout where delay lines are located on both sides of the anode plane. Since these delay lines enclose a field-free region, the need for a drift field conflicts with this. The situation can be only partially resolved by including another electrode within the delay line. Here, however, there will always be a small region where the field is in the wrong direction, creating dead volume.

3.2.3.6 Mechanical Complexity of Counters

Obviously one would prefer a simple mechanical arrangement of the various wire planes within the proportional counters. The fewer the number of wire planes the less expensive the counters will be. The minimum number of wire planes is two. In this case the windows are used as electrodes. However, with a drift field the two windows have to be at a different electrical potential which creates mechanical problems by itself. Therefore, a more realistic minimum number appears to be three wire planes. Some readout schemes could require as many as seven or eight wire planes.

3.2.3.7 Wire Material and Thickness

Mechanical properties of wires are of some concern, particularly when they get either very thin or very thick. Thin wires, like 0.5 mil diameter tungsten or stainless steel, are difficult to handle, break easily, and generally produce a reliability problem.

Thick wires create undesirable stopping power for X-rays, generating spurious events and tend to increase the thickness of the frames supporting the wires due to mechanical stresses introduced in the winding process.

Anode wire thickness is flexible to some extent and is mainly determined by proportional counter properties such as required gas gain, high voltage desired, wire spacing and anode to cathode spacing. Generally anode wire diameters between 0.8 and 2 mils are used.

The resistive wire readout technique forces the choice towards thinner wires in order to obtain a reasonable resistance. For delay lines one wants to minimize resistive losses in most cases, creating a preference for thicker wires.

3.2.3.8 Count Rate Capability

Proportional counter dead time is affected by the readout method. For an incident flux which is uniformly distributed over the whole counter area, the dead time is inversely proportional to the number of readout circuits employed. However, in the present case, it is expected that most counts will be concentrated in a few detector elements, arising from the small diameter of the flare regions. Therefore, the count rate problem cannot be significantly alleviated by employing a large number of readout circuits, since most of them would produce low count rates and only a few would handle the high flux from the flare region.

To first order then, the inherent signal processing times of the various readout methods determine the count rate capability of the system.

3.2.3.9 Background Rejection Capability

It is important to have an efficient scheme for rejection of the charged particle (electron and proton) background. Most environmental electrons will of course be passively shielded by the tungsten collimators. Some electrons are, however, created in the counter walls by interacting gamma's through the Compton effect. In addition fluorescence photons, particularly in the xenon counter, could escape to adjacent cells, thus confusing the position information.

In the layout as presently defined there are two sets of proportional counters behind each collimator--an argon counter followed by a xenon counter. This arrangement offers the opportunity of anticoincidence between these two counters. Charged particles which penetrate both counters will thus be effectively rejected. However, charged particles entering from the sides, and only hitting one detector, would not be rejected by this anticoincidence.

Such particles could be rejected by anticoincidence between individual cells. In a direct readout scheme the individual rows and columns defining the cells are available as separate signals. Mutual anticoincidence between rows and columns would thus provide cell-to-cell anticoincidence. The same technique is not available for delay line or RC-line readout because no individual signals for the elements can be identified. In fact these methods can only detect one pulse on the line at any instant and erroneous information is obtained when more than one event is registered on the line. However one can detect the occurrence of such multiple events by the constant delay time sum technique. This approach is applicable to both the RC-and LC-delay line schemes. It makes use of the fact that for a single event the sum $(t_0 - t_1) + (t_0 - t_2)$ is a constant, whereas for multiple events this sum is always less. Here t_0 is derived from the prompt pulse on the anode or on a cathode; t_1 and t_2 are the delayed timing pulses obtained from both ends of the RC- or LC-delay line.

Thus this technique effectively replaces the anticoincidence scheme discussed above for the direct readout methods.

A problem remains with particles stopping entirely within a cell. One solution for the identification of these events is pulse shape discrimination (PSD) as mentioned in Section 3.2.2.1. Its effectiveness in planar proportional counters is, however, less than in conventional cylindrical counters, first because of the electric field configuration which produces slower pulses in planar counters with a decreased difference in rise time between photons and charged particles. Second, there is a higher probability of a charged particle being parallel to the anode plane in a planar counter, than for it being parallel to the anode wire in a cylindrical counter. In both situations the charged particle produces a pulse with a fast rise time indistinguishable from a pulse resulting from a point charge.

Some charged particle events, which stop within a cell, will be rejected because their pulse height falls outside the range for the X-ray region (2 - 100 keV).

One remark on anticoincidence between argon and xenon counters should be made at this point. Since xenon counter pulses develop much slower than argon counter pulses (factor 5 to 10 slower) problems could develop at high argon count rates. The anticoincidence rate could then be so high that the xenon counter is effectively dead because of this. In the design of the windows, shutter and anti-coincidence logic this problem must be taken into account.

3.2.3.10 Electronics System Complexity

Total electronics system complexity is made up of individual circuit complexity multiplied by the number of circuits required. For the RC- and LC-line readout methods the circuits are relatively

complex when compared with the direct readout method. For the latter, however, the number of circuits required is several times that for the other two methods. In the HXII the minimum number of circuits for a direct readout method is $2 \times 6 = 12$ per proportional counter. This provides 36 spatial elements in a square array. For 15 argon and 15 xenon counters the total number of circuits would amount to 360 circuits plus other circuitry required for pulse shape discrimination, anti-coincidence, etc.

An all RC- or LC-line scheme would consist of anywhere from $3 \times 30 = 90$ to $5 \times 30 = 150$ circuits of higher complexity. It is a priori difficult to judge which solution provides the most science for the least cost. Representative schemes for both solutions are given in Section 3.2.5. It should be noted that intermediary solutions are possible as well, conceivably offering the potential of upgrading of the electronics as the HXII becomes operational.

3.2.3.11 System Flexibility

A very important consideration in the selection process should be the incorporation of system flexibility in the adopted solutions. For example in the construction of the proportional counters it would be valuable if various readout schemes could be implemented without changing the mechanical layout significantly. Another example would be the upgrading or changing of the electronics to improve overall performance in background rejection.

Closely tied to flexibility is interchangeability. It would be preferable to build only one basic proportional counter structure for both argon and xenon counters. Further, the adoption of a single wire frame which can be used for anodes, cathodes and drift field electrodes is strongly advisable. All of this will minimize design, fabrication, checkout and test costs as well as increase system reliability.

3.2.3.12 Functional Redundancy

Some readout implementations have a higher degree of functional redundancy than others. The direct readout schemes having several identical electronics circuits have a high degree of redundancy. When one set of electronics fails, a dead strip in the proportional counter results, still leaving the major capability to image intact. For a two-dimensional RC-line or delay line system, however, loss of electronics would result in elimination of the two-dimensional imaging capability. Some scientific performance would still be left in this case where the system basically would become one-dimensional.

3.2.4 System Tradeoff

We are now in a position to compare the various readout methods considered using the tradeoff criteria as operands. The first step is to identify those methods which must be eliminated from the start because of some overriding consideration.

3.3.4.1 Elimination of One-Dimensional Readout Schemes

As described in Section 3.2.3 the requirement for essentially square subcollimators eliminates one-dimensional readout schemes. These include one-dimensional delay line readout and one-dimensional RC-cathode readout.

3.2.4.2 Elimination of Two-Dimensional Delay Line Readout

This system, described in Section 3.2.2.1, is basically incompatible with the requirement for drift fields and for minimizing dead volume and mechanical complexity.

3.2.4.3 Evaluation of the Remaining Systems

In Table 3-1 we have listed the several remaining systems plus the evaluation criteria developed above. Each system receives a ranking from 1 to 5 as shown by the entries in the table. The ranking is to some extent subjective because not all ramifications can be overseen in a particular area. This is especially true in the rating for electronics system complexity. A detailed tradeoff involving cost, weight, volume, etc., of the electronics for two basic systems will hopefully resolve this dilemma.

An unweighted summation of the marks for the various methods identifies the direct readout schemes 4, direct anode readout combined with direct cathode readout and 5, direct cathode readout as winners. They are closely followed by the two-dimensional RC cathode readout, method 8.

Upon scrutiny of the difference between these systems it is evident that there is very little mechanical difference between them. This is also true with the next two systems: 7 one-dimensional RC cathode readout combined with direct anode readout, and 9 one-dimensional RC anode readout combined with direct cathode readout, which are hybrid solutions between direct and RC-line readout methods.

A zigzag wire plane differs from a direct readout plane only in the way the anode wires are interconnected (see Figure 3.2-11).

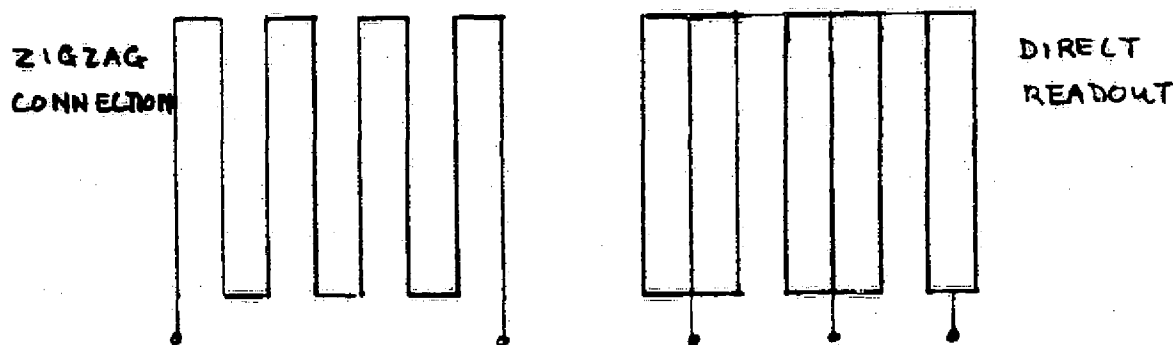
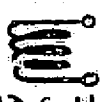
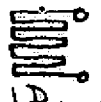
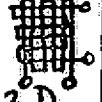
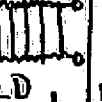
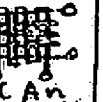


Figure 3.2-11 Wire Planes Differ Only in the Method of Interconnection

Table 3-1

Identification #	Delay Line Readout			Direct Readout		RC-Line Readout					
	1	2	3	4	5	6	7	8	9	10	11
Evaluation Criteria	 1D Cath.	 1D Cath. An.	 2D	 n An. in Cath.	 n Cath. in Cath.	 1D Cath.	 1D Cath. n An.	 2D Cath.	 1D An. n Cath.	 2D Anode	 RC An. in Cath.
1. Compatibility with subcollimators	0	5	-	5	5	0	5	5	5	5	5
2. Complexity of method	-	2	-	5	5	-	3	3	3	3	2
3. Spatial resolution capabilities	-	2	-	1	1	-	2	5	2	3	5
4. Susceptibility to crosstalk	-	4	-	5	5	-	4	5	4	4	1
5. Compatibility with drift field	-	5	0	5	5	-	5	5	5	5	5
6. Mechanical complexity	-	3	-	5	5	-	4	4	4	3	3
7. Wire material and thickness	-	3	-	5	5	-	3	3	3	3	2
8. Count rate capability	-	4	-	5	5	-	3	3	3	3	3
9. Background rejection capability	-	5	-	4	4	-	5	4	5	4	3
10. Electronics system complexity	-	2	-	4	4	-	2	4	2	4	4
11. System flexibility	-	3	-	5	5	-	5	5	5	3	2
12. Functional redundancy	-	3	-	5	5	-	3	2	3	2	2
TOTAL	-	41	-	54	54	-	44	48	44	42	37

So all five schemes ranked highest can be retained as possible solutions for the readout problem from a mechanical point of view.

As pointed out, the main difference is in the electronics required in each case. If there turns out to be a substantial cost differential between the electronics then a comparison of the performance of each system from a scientific and technical point of view should ultimately produce the preferred solution.

Some discussion on two electronics systems which are at both ends of the spectrum follows in Section 3.2.5. Intermediate solutions could result with the adoption of hybrid readout schemes as mentioned above.

3.2.5 Readout Electronics

The two basic readout schemes resulting from the tradeoff are outlined in schematic form in this section. More detailed investigations of how to implement various features and the detailed cost evaluation should be made.

3.2.5.1 Direct Readout

The electronics required for the direct readout schemes of solutions 4 (n anodes, m cathodes) and 5 (n cathodes 1, m cathodes 2) is very straightforward, although a large number of circuits is required. Figure 3.2-12 gives the schematic block diagram of the electronics required for one of the 32 proportional counters.

In the system sketched, the anode plane provides the energy information of the x-ray event to the pulse height analysis chain. A lower level discriminator (LLD) and an upper level discriminator

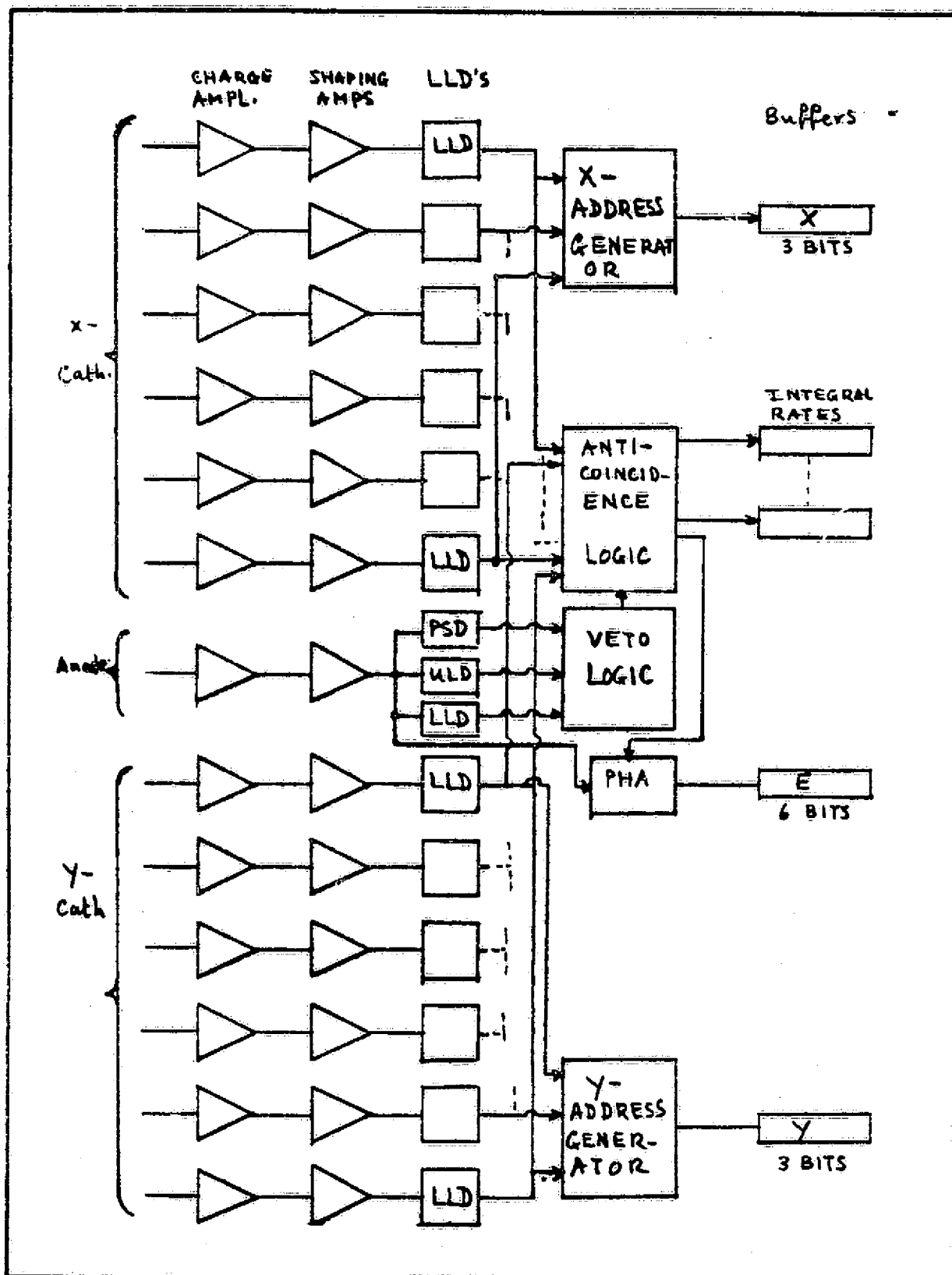


Figure 3.2-12
Direct Readout Electronics

(ULD) set acceptable limits (2 to 100kev) on the energy of the event. In addition, a pulse shape discriminator (PSD) will reject events which have an anomalous rise time.

These three outputs are combined in the veto logic to provide an inhibit signal to the pulse height analyzer (PHA).

The spatial information is obtained from the two cathode planes where wires are connected in six groups in each plane to provide $6 \times 6 = 36$ spatial elements. The signals induced on the cathode wires are charge integrated, shaped and discriminated by an LLD which provides logic signals. These signals are used to provide the two spatial coordinates by the x- and y- Address Generators. In addition, the Anticoincidence Logic detects when more than one row and/or one column of wire groups registers an event.

The three pieces of information: x-and y-positions and E, energy of the event are temporarily stored in buffers. In addition, integral count rates are made available.

3.2.5.2 RC-Line Readout Electronics

Figure 3.2-13 shows a block diagram of representative electronics for one detector using two zigzag RC-cathodes. The anode pulse is integrated in the preamplifier and followed by a shaping amplifier which feeds four discriminators. The Constant Fraction Discriminator (CFD) provides the timing reference t_0 , independent of pulse amplitude, which is used as the start pulse for the two Time-to-Height Converters (THC) in the X- and y- position encoding systems. LLD, ULD and PSD generate outputs used by the veto logic in the same way as described for the direct readout electronics.

The two cathodes provide delayed output signals dependent on the position of the event in the x-y plane. Voltage amplifiers connected to both ends of the two cathodes are followed by a filter amplifier

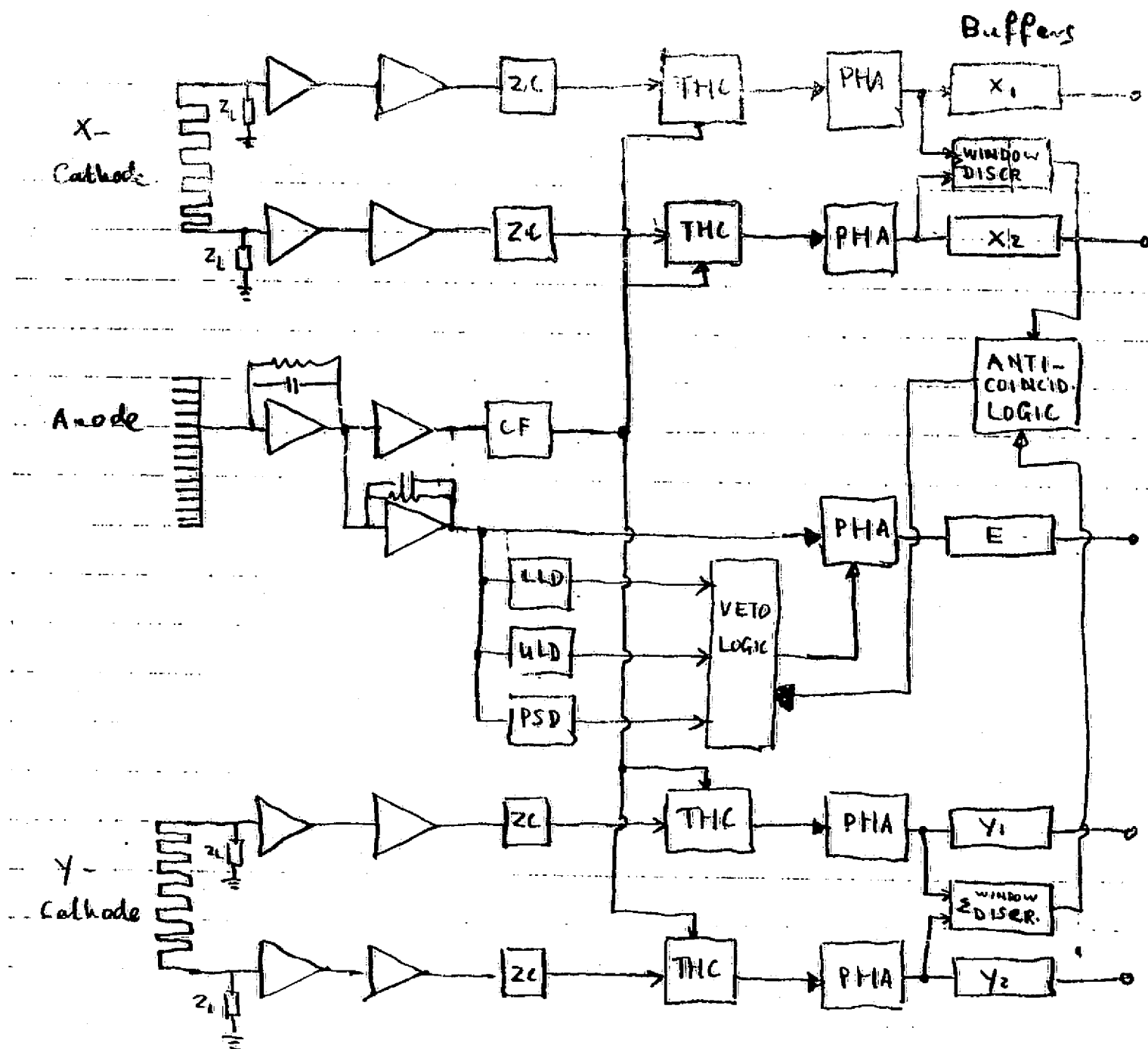


Figure 3.2-13 RC-Line Readout Electronics

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which generates a bipolar signal. Zero-crossing discriminators generate the stop pulses for the THC's which are started as described above by the anode CFD signal.

In figure 3.2-13 we have shown identical sets of electronics connected to both ends of both cathode planes. Strictly speaking, only one end of each has to be connected to provide the x- and y- position signals. However, using the two complementary position signals x_1 , x_2 , y_1 and y_2 and requiring that their sums $x_1 + x_2$ and $y_1 + y_2$ be constant we can detect the presence of multiple events on the lines. This feature thus essentially performs the anticoincidence function as indicated in the figure.

3.2.6 Proportional Counter Mechanical Configuration

In order to obtain a reasonably accurate weight and cost estimate, it was necessary to study the mechanical requirements for the proportional counters (PC's) in some detail. The results of that study are reported in this section.

In the structural design study, it was determined that the collimator grids would be divided structurally in four equal-area sections to provide maximum open transmission area. It became obvious that four gas containers maintained this advantage over separate gas chambers for each collimator. Within each of the four gas chambers is a separate multiwire detector for each collimator (total of 14). Figure 3.2-14 shows a layout of a typical pair of chambers, detectors, and collimators.

The mechanical design of a PC is based entirely on stress analysis. The stresses were determined as follows:

- Wire preload tension;
- Frame size to support wire loads;
- Housing frame size to support gas pressure;
- Egg-crate collimator cell size to support window.

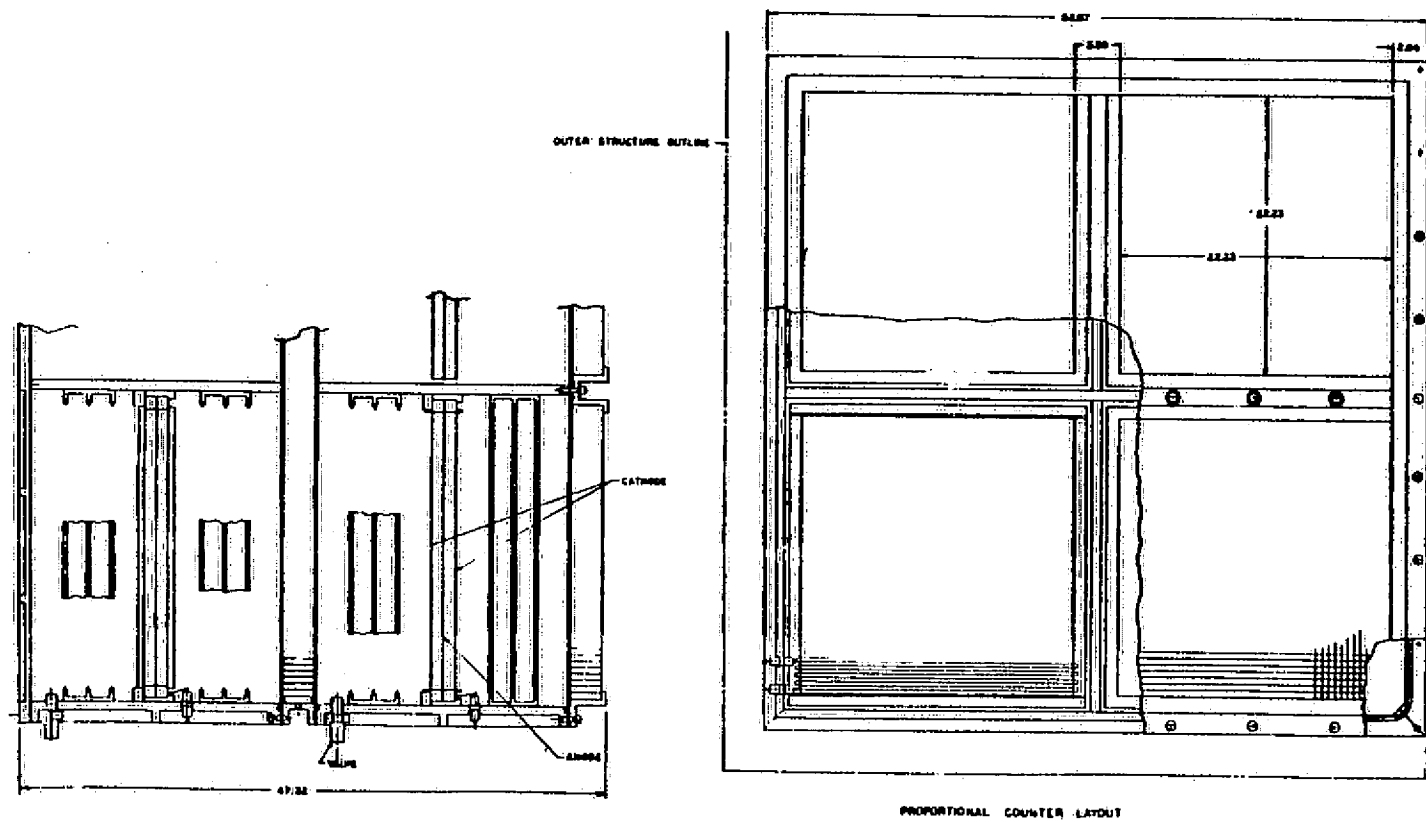


Figure 3.2-14

The results of these calculations are given in the following subsections. The detailed analyses are given in the appendix.

In addition, a subsection is included on window materials and another on materials in general for within the gas chamber. A summary of conclusions and recommendations follows.

3.2.6.1 Tension on Anode and Cathode Wires

A worst case of 1-mil anode and 3-mil cathode wires, both 304 stainless steel, was assumed.

A preload stress of 2900 psi on the 1-mil wires will prevent them from oscillating in a 4-kV voltage field. It will not prevent them from going slack in the temperature range.

The preload was selected to be 15,000 psi. This is provided by 5.4 grams force when welding the wires to the frames. Maximum preload is 20,000 psi at maximum temperature.

A preload of 5.7×10^{-3} grams force prevents oscillations for the 3-mil wire. A force of 48 grams was selected, for a nominal tension of 15,000 psi.

3.2.6.2 PC Wire Frame Sizing

The force due to the preceding wire loads, for wires spaced 0.25 cm, is negligible. The frames must have sufficient material to have fastener holes.

A frame section of 1 cm thick by 0.75 cm wide was assumed. Maximum deflection of 6.3×10^{-5} inches was calculated, assuming a glass-bonded mica ceramic frame material.

3.2.6.3

PC Housing Frame Analysis

The quadrant-sized PC gas chamber housing must have internal tension members at the midpoints, otherwise excessive deflections will occur. Deflections must be minimized at the midpoints or the wire frames will be distorted and wires overloaded. One-quarter-inch aluminum plates are adequate to prevent this from occurring.

For a reasonable housing side wall section (less than or equivalent to a one-inch aluminum plate), the remaining midpoints deflect sufficiently to fail a 2-mil beryllium window. Therefore, additional tension support is required.

It was concluded that if the egg-crate collimator is brazed to its frame, this assembly can provide the tension required. Then the side wall sections can be shown in Figure 3.2-14. Time and money did not permit a computer model to be made and analyzed to prove this idea.

3.2.6.4 PC Egg-Crate Collimator Size

Calculations were made using flat-plate theory for the maximum square cell size for a 5-mil beryllium foil window. Using a factor of safety of 2 for yield stress gave a cell size of 4.7 mm, for a pressure of two atmospheres.

Again using flat-plate theory, it was found that a solid aluminum plate 6.9 mm thick would deflect 0.13 mm, the maximum allowable. The moment of inertia of a section 4.7 mm wide by 6.9 mm high was determined. An equivalent moment of inertia for a section 0.25 mm wide requires a height of 18 mm. Hence, the egg crate can be made up of 0.25-mm-thick aluminum strips, 4.7 mm apart (square) and a minimum of 18 mm high.

The same analysis was made for a 2-mil parylene window. Since this is an elastic material, the calculations for cell size were based

on membrane stresses. The cell size came out to be the same as for the 5-mil beryllium. However, the parylene will deflect 1.5 mm into each cell.

3.2.6.5 Window Material

Vendors were contacted about beryllium foil. Neither of the two manufacturers contacted who supply it would guarantee 2-mil foil to be vacuum tight. The beryllium grain size is on the order of 1 mil, and in rolling the foil, one or more grains may be crushed, resulting in through-cracks. Five-mil foil is guaranteed vacuum tight. Maximum sizes available are 20 cm by 20 cm and 12.7 cm by 30.5 cm. Neither size is large enough for HXII (23 cm by 23 cm maximum)

Several beryllium metal fabricators were contacted to determine the metallurgical method most suitable for this design approach; however, at the 2-mil foil thickness range we are approaching the basic grain size from the sintered material crystal geometry. As a result the practicality of achieving a completely leak-free window is quite doubtful without enormous costs which could not even be accurately estimated. The most likely method, should it be required, would be a combination of electron beam welded joints of etched sheets of 0.01 beryllium.

Parylene has been successfully used for gas chamber windows. From a fabrication and cost view, this or mylar appears the preferable window material.

3.2.6.6 Materials Within the Gas Chamber

The gas chambers are to be sealed during operation. The gas is easily contaminated, particularly by water vapor and organic out-gassing materials.

During the study, glass-bonded mica machinable ceramic was investigated for the wire frames and other required insulators. Sketches of parts were sent to suppliers for cost estimates. Only one supplier responded, but it appears reasonable in cost. It was anticipated that a suitable metal would be plated on the frames and the wires resistance welded to the plating. In a follow-up conversation, it was learned that metallizing is difficult. It adheres to the glass bond but not to the mica. The supplier was to investigate the plating problem but to date has not reported back.

An alternate suitable material is ordinary electrical-insulating-type alumina ceramic. Because it has to be diamond ground, the cost would be greater.

Viton "O" rings will provide suitable sealing. A gas chamber contains 5×10^6 cc. A 1×10^{-4} cc/sec leak rate would leak 60 cc in a 7-day mission. It is estimated that a leak rate of 10^{-6} cc/sec can readily be attained with the "O" rings. Viton can be baked out to reduce the possibility of contaminants.

3.3 SIPS/INSTRUMENT INTERFACE

A SIPS/Instrument mechanical interface has been suggested (see Section 3.1) and a maximum instrument length of 3.2 meters baselined. The maximum SIPS canister length is limited to just over 3.3 meters by the gimbal and yoke configuration. However, the Spacelab pallet length is significantly less than 3 meters so that interference with large instruments on adjacent pallets is a potential problem for a 3.3 meter canister. The unknown factor is the spacing between adjacent pallets which is TBD at this time.

Although the conceptual 'standard' SIPS canister is a thermal and contamination shroud, it is not a support structure and will not support electronics packages or RAU's. The use of a 3.3 meter SIPS canister has been baselined for the HXRF for thermal and contamination protection. Mounting of electronics boxes or RAU's must be on the gimbal frame or instrument structure if the number of interfacing wires prohibit mounting on the Spacelab pallet. Similarly, sun sensors and/or star trackers must be mounted on the gimbal frame or instrument structure. An HXII unique gimbal fraem has been proposed which could be designed to accommodate electronics and sensor packages at the expense of additional mass to be pointed.

Locating the RAU on the pallet has the advantage of minimizing size and weight on the gimbals, but again the wire bundle required between the electronics box and the RAU may be prohibitive for the SIPS. The current estimates for the RAU size and weight are 5.5 inches x 6.2 inches x 15.8 inches and approximately 20 lbs.

The SIPS/Instrument thermal interface was not considered in this study, but it is reasonable certain that the $20 \pm 1^{\circ}\text{C}$ canister thermal control option will be required by the HXII.

Another SIPS/Instrument interface which will require further definition is the way in which the SIPS and HXII micro-processors work together. Section 4.3 outlines some of these considerations.

This section describes the configuration of the instrument recommended as a result of this study. Included is a weight breakdown, and a description of how to potentially balance the instrument for a centered mass positioning control system.

Figure 4.1-1 shows the initial balanced recommended configuration. The grids are coordinated with the proportional counters for maximum viewing area: each collimator is 22.225 cm square, giving 6915 cm² for the 14 collimators.

4.1 STRUCTURE DESIGN CONCEPT

The potential structure is an open frame truss. At the front and rear, a bulkhead with open areas equal to the grids is required to prevent twisting of the square structure. The center structural webs are sheets of aluminum. The gimbal frame is an integral part of the structure. The proportional counters are mounted in tandem on the rear of the structure and each gas chamber covers one quarter of the area cross section.

For thermal control, the truss portion of the structure will be covered with multi-layer insulation blanket.

The structure may not be sufficiently rigid to permit alignment and alignment checkout of the grids in a horizontal position. However, further analysis with a math model may show it can be made sufficiently rigid by redistribution of structural elements. The math model used in this study treated all joints as pinned joints. By using patch plates at all truss joints, rivets could be patterned to approach fixed end conditions.

C-3

4-2

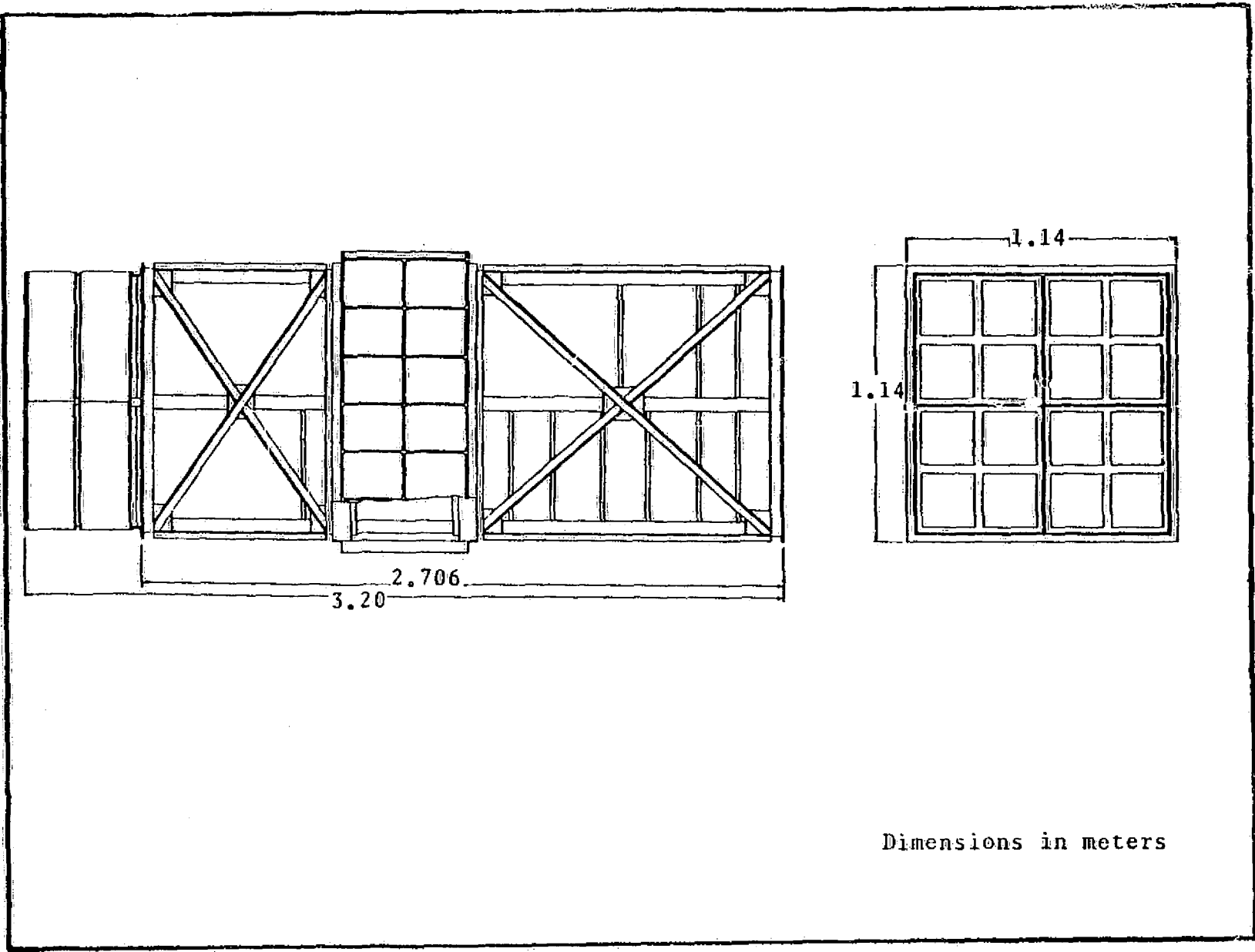


Figure 4.1-1 Final Structural Concept for IIXII

4.1.1 Weight Breakdown

Table 4.1-1 gives the major component weights. These figures are the weights after the weight-relieved numbers are applied. In the case of the grids, the weight relieving includes the subcollimator slits, where 50% is open area. On the basis of the analysis performed in the study, it is believed that these weights are achievable.

Table 4.1-1
Weight Breakdown

<u>Item</u>	<u>Weight (kg)</u>	<u>Weight Relieved</u>
Proportional Counters	109	25%
Structure	84	---
Grids (109 @ .794 kg)	86.8	33%
Grid Support Frames (31)	61.3	25%
Gimbal Frame	45.5	---
Thermal Shield*	73.0	---
Aspect System and On Gimbal Electronics	40.4	---
Total	500.0	

*Door, mask, covers and heaters

4.1.2 Balance

The ground rules for the grids are that there is a grid at the front and at the back of a collimator. The distance between these two is L . The next grid is located at $L/2$. The next grid is located at $L/4$, but it may also be located at $3L/4$. The next grid is at $L/8$, or 3 , 5 , or $7L/8$, and so forth. All but the end and center grids may be located either in front or behind the center grid, or any mixture of both. This allows ample provision for balancing MXII. One other ground rule is that provision must be allowed for access to adjusting mechanisms.

An exercise produced one iteration at balancing the mass of the proportional counters. Of interest is to see the CG move forward from the initial structure CG as each quadrant of grids is added. This exercise left the CG 1.15 cm from the gimbal axis, but did not include the aspect system, which probably will be at the front end. It shows that there is great flexibility and no ballast weight need be used.

Alternately, the grids can be located in a similar manner to optimize an end-pointing control system at the instrument level. The basic structure may additionally be designed such that both a balanced or an end-pointing control system can be used by optimizing the grid positioning to affect the mass moments.

The selection of the spatial readout method for the proportional counters was treated in the trade-off analysis of Section 3.2. The resulting proportional counter layout is still flexible and can be optimized to give the best performance within the constraints imposed by the scientific requirements.

The tradeoff analysis resulted in a counter with two cathode planes with orthogonal wire directions, read out in six groups each, to provide the spatial elements, with the anode plane used for energy and pulse shape discrimination. Remaining to be determined are all physical parameters such as distance between anode and cathode planes, wire spacings, wire diameters, location of the wire planes in the counter, and total counter thickness. In addition, we need to determine the gas pressure to be used in the counters, high voltages required, etc.

4.2.1 Proportional Counter Thickness and Gas Pressure

Strictly speaking the argon and xenon counters can be of different design in terms of thickness and gas pressure. However, it appears that considerable cost savings can be obtained if the argon and xenon counters are identical in physical dimensions and in the pressure to be used. There would be the obvious advantages in identical drawings, reduction in the number of spare modules required, and interchangeability of counters, which all contribute to lower total cost. In this case the overall thickness of the counters is determined by the efficiency of xenon for the higher energy X-ray photons. In Figure 4.2-1 is shown the detection efficiency for argon and xenon at a total gas thickness of 40 atm. cm.

It should be noted that the detection efficiency shown in Figure 4.2-1 is not the same as the spectral response of the detectors, particularly for the xenon. A photon above the xenon k-edge

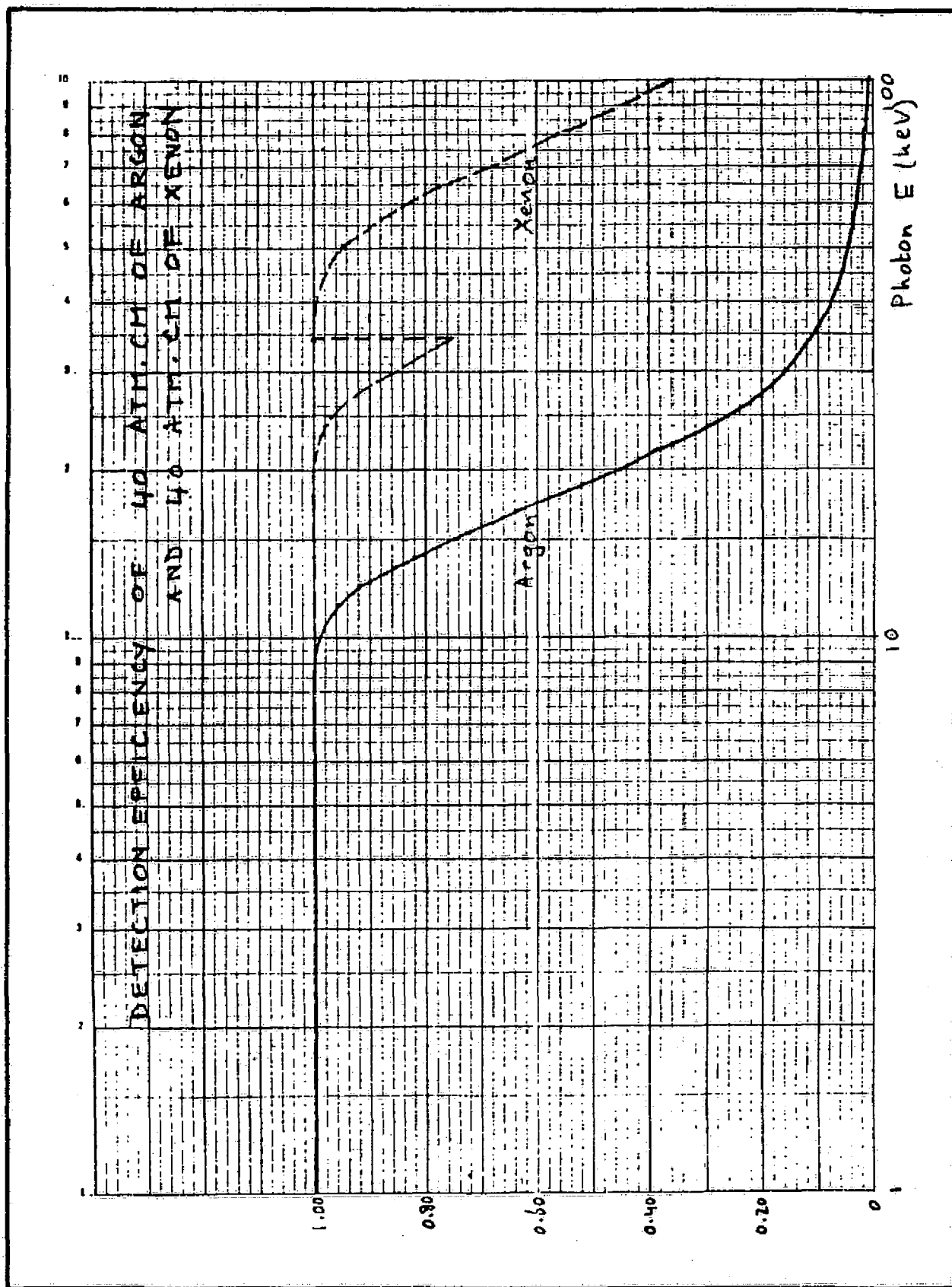


Figure 4.2-1
Gas Detection Efficiency

of 34.59 Kev has a probability of 89% of creating a 29 Kev fluorescence photon. This fluorescence photon introduces spectral distortion if it escapes from the gas volume. The probability of escape depends on the location of the interaction of the primary photon and on the geometry of the counter. If the fluorescence photon is absorbed at another point in the gas volume, the total energy deposited is still representative of the energy of the primary photon. However, if these two interactions occur at widely differing depths, the counter treats them as two separate events leading to two separate pulses. In addition of course, a spatial distortion is introduced by the fluorescence photon. For these reasons the detection efficiency for xenon as shown in Figure JE-20 is not truly representative of the proportional counter response. For a detailed analysis of the spectral and spatial distortions introduced by the fluorescence effect as a function of proportional counter geometry and pressure, a Monte Carlo simulation must be performed.

A very significant problem for detectors for solar X-ray physics arises from the steepness of the solar X-ray spectrum which, between 1 and 100 Kev covers some 10 orders of magnitude in photon flux. It must be understood that a good efficiency at 3 Kev is a requirement because of the need to observe cosmic X-ray sources for observational as well as alignment purposes. The counter window can therefore not be made thick in order to attenuate the low energy solar X-ray flux. This creates an extremely high count rate in the argon counter during solar flares. From the start it was clear that the requirement of good efficiency at low energy X-rays and a reasonable count rate in the proportional counters could only be solved by some kind of variable geometry, such as a shutter, to be operated during flares.

UCSD used their existing computer programs to analyze several combinations of shutter, window, argon and xenon gas thicknesses with the objective of reducing the overall count rate during flares while maintaining good efficiency at 3 Kev for cosmic

sources and the quiet sun, as well as having a good efficiency from 50 to 100 KeV. The final result of this exercise is shown in Figure 4.2-2. Here the solar input spectrum is indicated for a plasma with an emission measure of 10^{50} (cm^{-3}) and an electron temperature of 1.5×10^7 °K. The non-thermal component is characterized by a power spectrum with a slope of -4 and a value of 10 photons/sec-keV- cm^2 at 20 KeV. This event is expected to occur on the average once every 10 days.

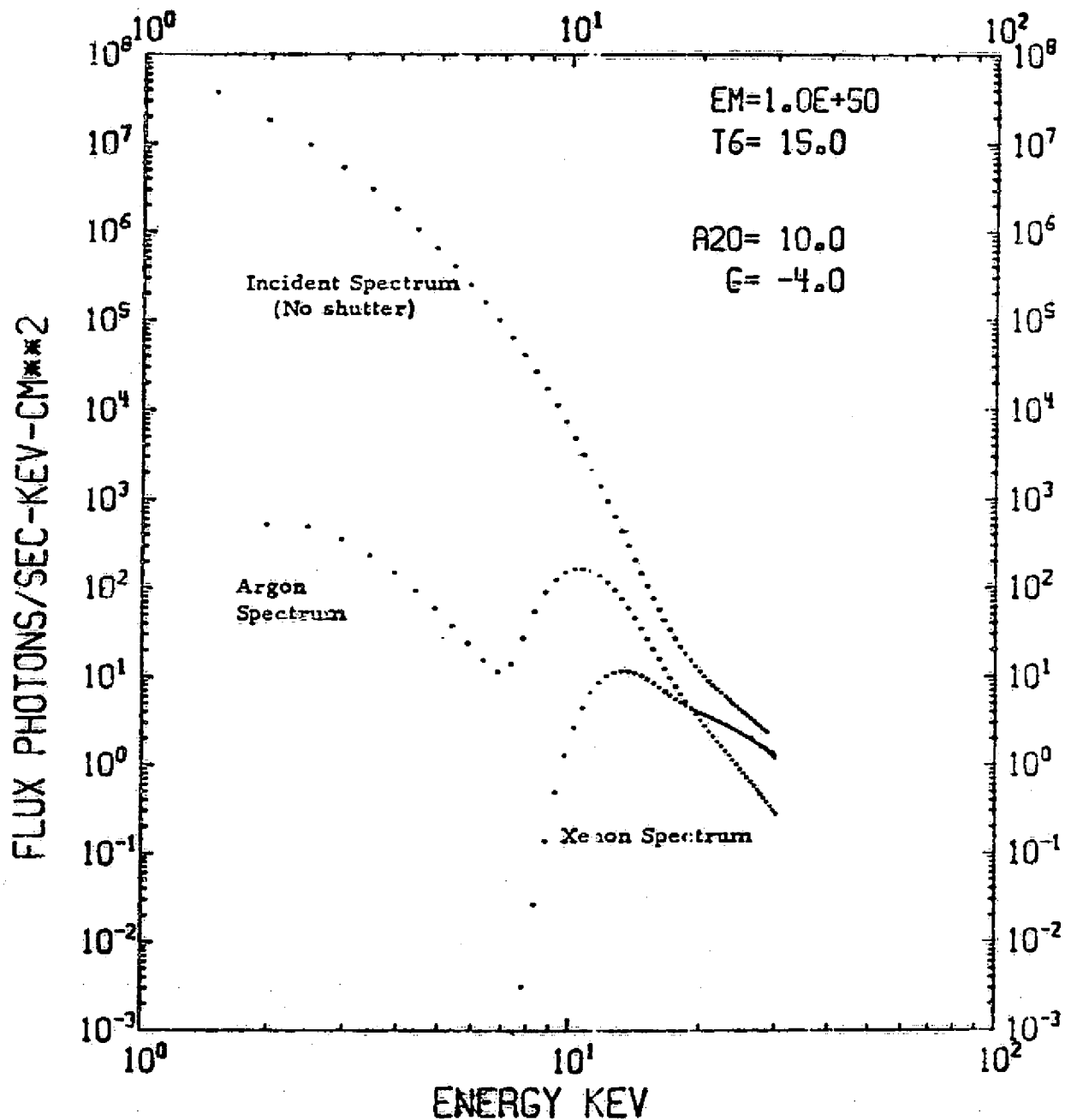
An aluminum shutter of thickness 5.08×10^{-2} cm (20 mils) with open area of 10^{-4} (realized by holes in front of all spatial elements of the proportional counters) serves to attenuate the low energy photon flux while essentially transmitting the higher energy photons. The assumed entrance window consists of 5 mil beryllium. It can be seen that the spectrum incident on the 40 atm.-cm thick argon counter has been flattened out considerably in this way and that the total count rate in the argon counter is 1.87×10^3 counts/sec- cm^2 . The 40 atm.-cm thick xenon counter is located behind the argon counter and has a total count rate of 105 counts/sec - cm^2 .

Because one subcollimator has an effective area of about 3.3 cm^2 the count rate per spatial element in the argon counter is 6.17×10^3 per second for this flare. Most counts will be located in a few subcollimators so that the maximum count rate in the argon counter will be of the order of 2×10^4 per second, which is a reasonable number for an argon counter.

This effort of optimizing the proportional response thus resulted in the total gas thickness of 40 atm -cm for the xenon counters and from the desire of keeping argon and xenon counters the same, this same 40 atm.-cm was specified for the argon counters.

The next step was to determine the absolute gas pressure in the counters. This must be a compromise between the problems introduced

TEST RUN SHUTTER-WITH-HOLES



AL= 5.08E-02 BE= 1.27E-02 FR= 4.00E+01 XE= 4.00E+01
AR #= 1.87E+03 XE #= 1.05E+02 HOLES= 1.0E-04

Figure 4.2-2 Solar X-Ray Spectrum

by high pressures and the advantages of lower pressures. The problems result from the following considerations:

1. Gas Physics:

- a) Proportional counters, and in particular xenon counters, are susceptible to contaminants such as oxygen and water vapor. This susceptibility increases with pressure. The effect shows up in deteriorating energy resolution (due to recombination) and decreasing gain.
- b) The gain of the counter is an inverse function of the pressure. To maintain a certain gain the voltage applied between anode and cathode must be increased as the pressure is increased. Higher voltages create spurious breakdown problems, in the proportional counter, close to the edges, around feedthroughs and outside the counter in the high voltage components.
- c) The rise time of the anode pulse increases with pressure, decreasing the rate handling capability of the proportional counter system.

2. Mechanical:

- a) Since the square cross-section of the proportional counters does not lend itself very well for a pressure vessel design, a weight penalty has to be paid for increased pressure.
- b) Window design becomes a limiting factor, such as in the case of beryllium which cannot be readily obtained in large areas below 5 mil thickness. The window support, in this case an egg-crate type structure, has to be increased with increasing pressure by reducing the cell size. This creates additional dead area.
- c) Safety becomes an area of increasing concern with increasing pressure.

A careful weighing of these factors leads us to a compromise pressure of nominally 2 atmospheres, resulting in a nominal counter thickness of 20 cm. Operation of xenon counters (90% Xe - 10% CO₂) has been reported by Borkowski and Kopp (1975b) at 6 atmospheres of pressure, so we do not expect significant problems at 2 atm.

We already discussed the need for drift regions in proportional counters of this thickness in Section 3.2. The requirements for spatial resolution, although not severe, nevertheless must be of the order of a few millimeters for an unambiguous identification of the spatial element in which the X-ray photon registers. This leads to a maximum anode wire spacing of a few millimeters which in turn leads to a maximum anode-to-cathode wire plane spacing of 5 to 10 mm. Therefore the bulk of the counter thickness must be drift region with the proportional region on the order of 1 to 2 cm thick.

We still have the choice of locating the proportional region symmetrically within the counter, or asymmetrically such as close to the window. We have chosen to locate the proportional region in the center of the counter for the following reasons:

- a) The maximum drift length is then about 9 cm, rather than 18 cm. This keeps down spatial uncertainties due to diffusion and non-normal incidence. Diffusion is proportional to the square root of the drift length. The effect of non-normal incidence, which produces an apparent displacement of the registration of the photon interaction, which is a function of the depth of the interaction, is proportional to the drift length.
- b) Symmetrical location allows a symmetrical electric field configuration. This reduced the overall voltages required and also reduces the number of different voltages required to set up the proper fields for drifting.

4.2.2 Proportional Counter Configuration

As a result of the above considerations we arrive at the proportional counter configuration shown in Figure 4.2-3.

The two counters are nominally 20 cm thick at a pressure of 2 atmospheres of argon and xenon respectively. The proportional region of about 2 cm thick uses a nominal voltage of about 4 Kv.

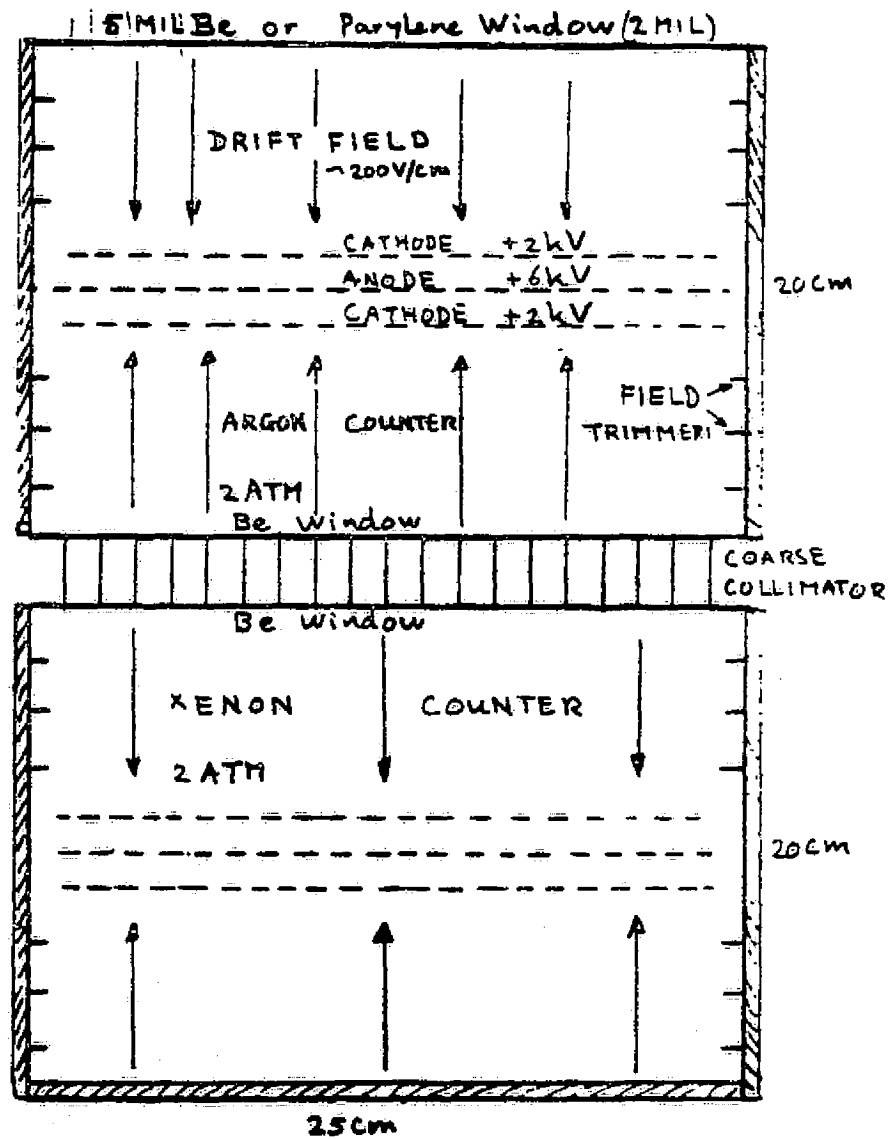


Figure 4.2-3 HXII Proportional Counters

On both sides of the proportional region are located 9 cm deep drift fields with an electrical field strength of about 200 v/cm. Field trimmers close to the counter walls are used to minimize fringing fields and spatial distortions.

The entrance window to the argon counter can be either 5 mil beryllium or made of a material like Kapton or Parylene in a thickness of about 2 mils. The choice of the final material for the window will have to take into account the need for a bakeout at elevated temperatures to remove harmful contaminants. The window is supported by an eggcrate structure. The backside of the argon counter and the front window of the xenon counter are beryllium of about 50 mils thick, and are separated and mutually supported by a coarse collimator made of the same eggcrate material that supports the entrance window.

An exploded schematic view of the detector is given in Figure 4.2-4 which shows the orientation of the anode and cathode wire planes, as well as the readout of spatial coordinates.

4.2.3 Proportional Counter Operation

For clarity we briefly review what happens when a photon is absorbed in the drift region, assuming that it is converted photoelectrically, producing a primary electron with energy equal to the photon energy minus the electron binding energy. This primary electron will quickly lose its energy by creating secondary electrons along a tortuous path whose projected length is of the order of 2 to 3 mm for a 50 KeV photon in 2 atmospheres of xenon and 1.5 to 2 mm for a 20 KeV photon in 2 atmospheres of argon. The number of secondary electrons created is equal to $h\nu/w$, where w is the energy required to create an electron-ion pair. For P₁₀ (90% argon - 10% methane) $w = 26.3$ eV and for 90% xenon - 10% methane $w = 21.7$ eV.

The cloud of electrons is subject to the force imposed by the drift field and moves towards and through the cathode plane from whereon it sees the higher electric field in the proportional region. As the cloud of electrons approaches the anode wire the electric

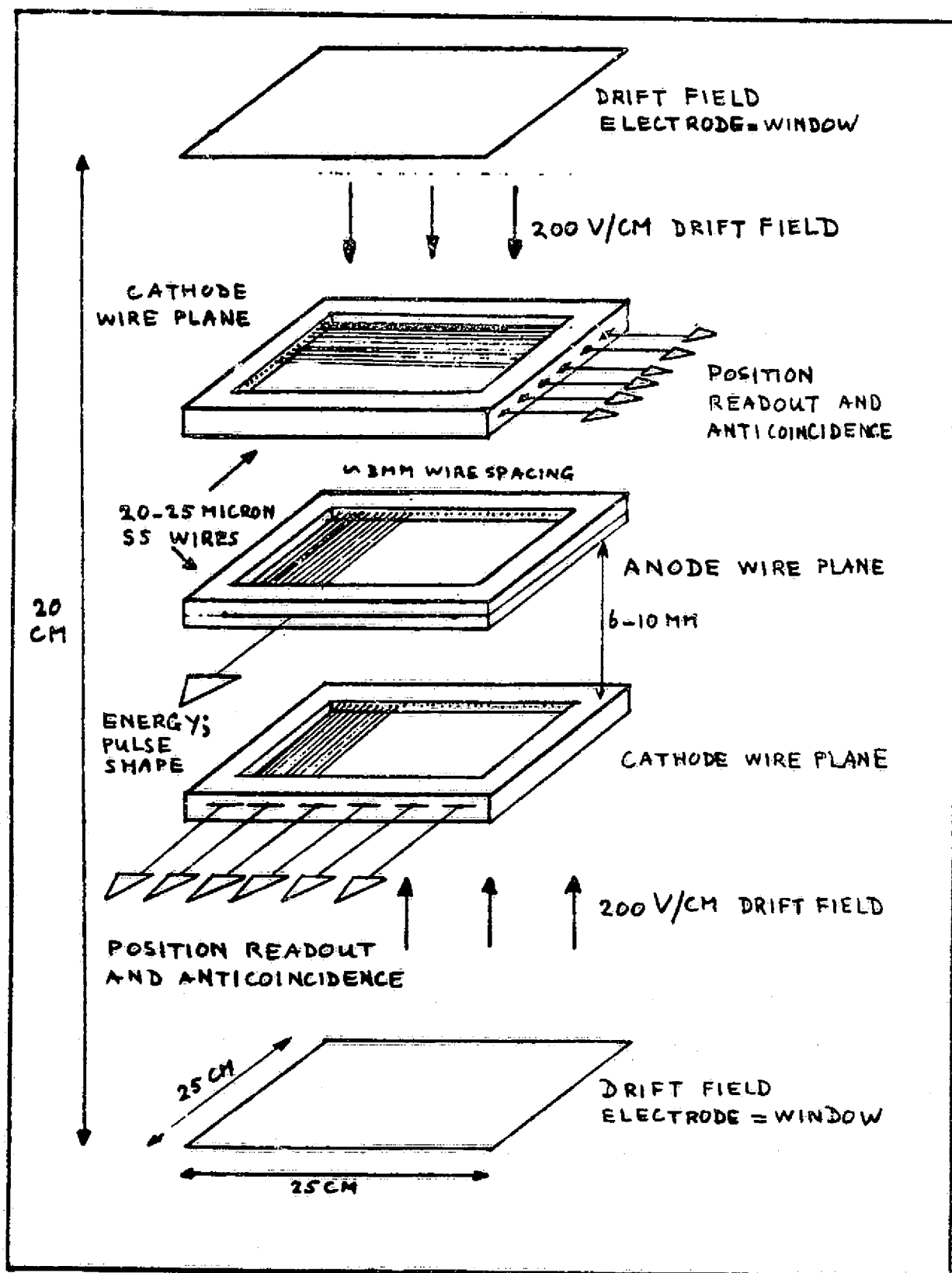


Figure 4.2-4 HXII Counter Layout

field strength increases and the electrons accumulate enough energy to produce additional electrons through ionization of gas atoms. This multiplication process accelerates and mostly takes place within a few anode wire diameters. Space charge created this way assures that the ions are distributed around the anode wire in cylinder symmetrical fashion. The electrons are quickly collected by the anode. The ions, being much slower, move away from the anode, and in doing so induce a voltage on the anode wire and on all surrounding conductors, including neighboring anodes and cathodes. The total induced charge on all conductors must be zero, of course. The induced charge pulses can be integrated by charge-sensitive preamplifiers and subsequently pulse height and pulse shape analyzed.

It will be evident that ionizing particles, which leave an extended track in the proportional counter/drift region, will produce pulses which have a long rise time. This feature can be used to discriminate against and reject charged particles.

4.2.4 Proportional Counter Front-End Electronics

The anode plane pulse is collected by a charge integrating pre-amplifier as shown in Figure 4.2-5. This is followed by a voltage amplifier and a shaping amplifier stage to create a pulse shape suitable for pulse height analysis. The output of the voltage amplifier is also routed to a pulse-shape analyzer (PSA) and pulse shape discriminator (PSD).

The pulse height analyzer converts the height of the shaped pulse into a pulse width which is subsequently converted into a digital number by the Time-to-Digital Converter shown in Figure 4.2-5b.

The two cathode planes are each divided into six groups of wires. Induced pulses on these wire groups are collected by charge-sensitive preamplifiers, followed by voltage and shaping amplifiers. Finally one of the six low level discriminators (LLD) in each direction will trigger to indicate X- and Y-position of the X-ray event.

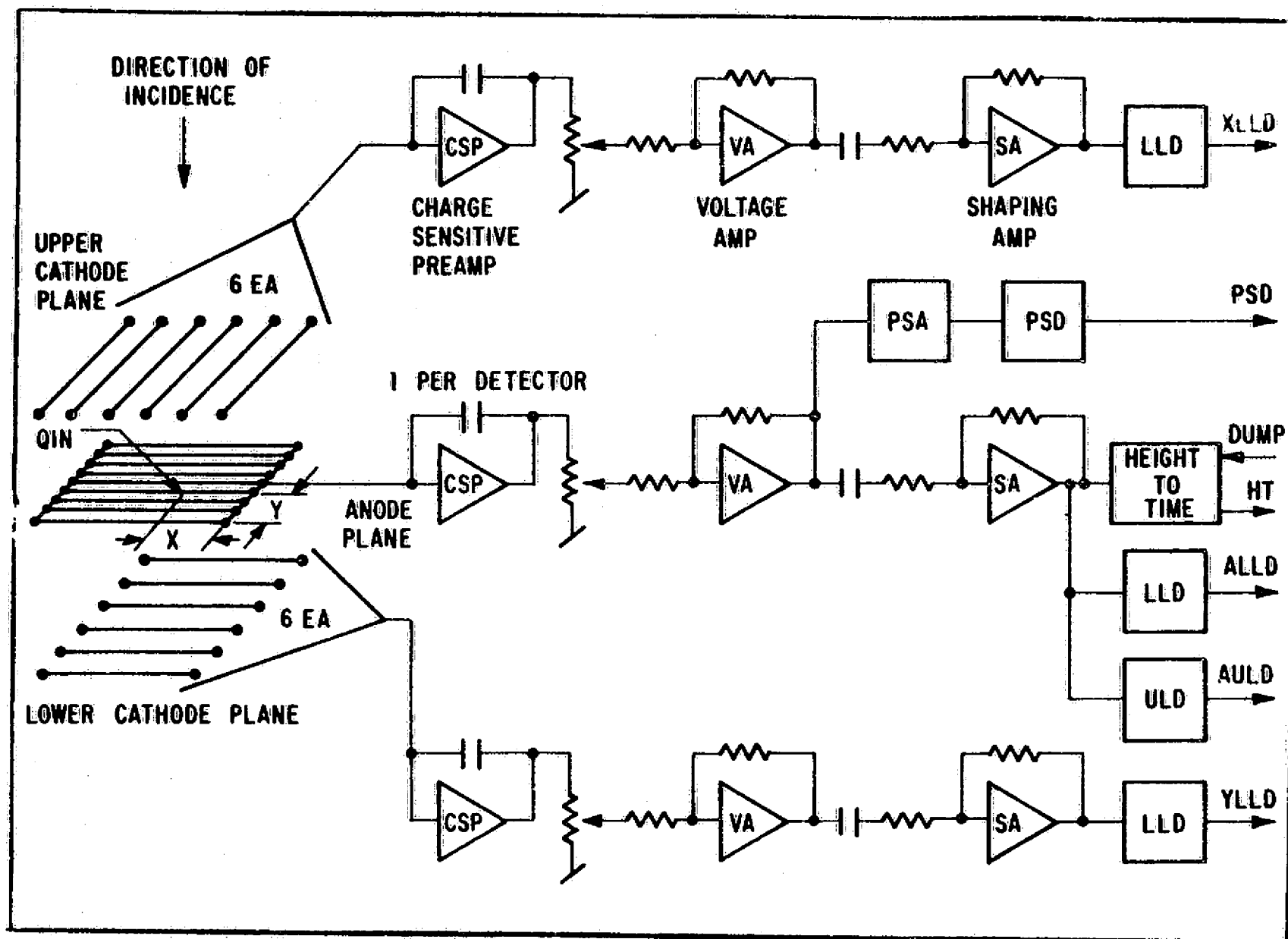


Figure 4.2-5 HXII Front-End Electronics

The output of the shaping amplifier in the anode chain also goes to an LLD and a ULD, upper level discriminator, to determine whether the event is within the energy range of the detector. The output of the anode lower level discriminator (ALLD) is synchronized to a digital clock and normalized to a width defined by an integer number of clock periods. The normalized LLD (NLLD) time correlates other digital signals relevant to the detector's X-ray event. These signals are input to the first rank latch. The first rank latch is cleared when the NLLD output appears. Immediately following the clearing operation, inputs are sampled. If an input is valid at any time during the short sampling window, that information is stored in the latch. The time-to-digital converter is busy converting the pulse height into a number. Also, the veto logic, which is programmable to accommodate various coincidence and anti-coincidence schemes, determines whether the event is acceptable.

The X- and Y- position are converted into a single position number identifying which spatial element gave rise to the event. If the event is acceptable, an event strobe is generated. The event time and position codes and first rank discriminator data are then stored in the second rank latch to await the completion of the time-to-digital conversion of the pulse height. When conversion is complete, second rank data, PHA value and detector identification codes are loaded into the μ P buffer register to await transfer to the event steering logic. The front end logic may begin processing a new event when the μ P buffer register is loaded. In case of an invalid event, the pulse height information is dumped, and an event strobe is not generated.

The anticoincidence scheme includes cell by cell anticoincidence as discussed in Section 3.2. Also, the argon and xenon counters are operated in mutual anticoincidence. To be investigated further during a future study is the matter of additional anticoincidence capability by using guard wires close to the proportional counter walls which would see induced pulses from Compton electrons created in the walls. In addition it needs to be considered whether a separate anticoincidence section close to the argon counter window would be required and be acceptable. Here the increased protection for Compton electrons created in the collimator and window must be weighed against the reduced efficiency at low energy photons because of the absorption in such an argon layer.

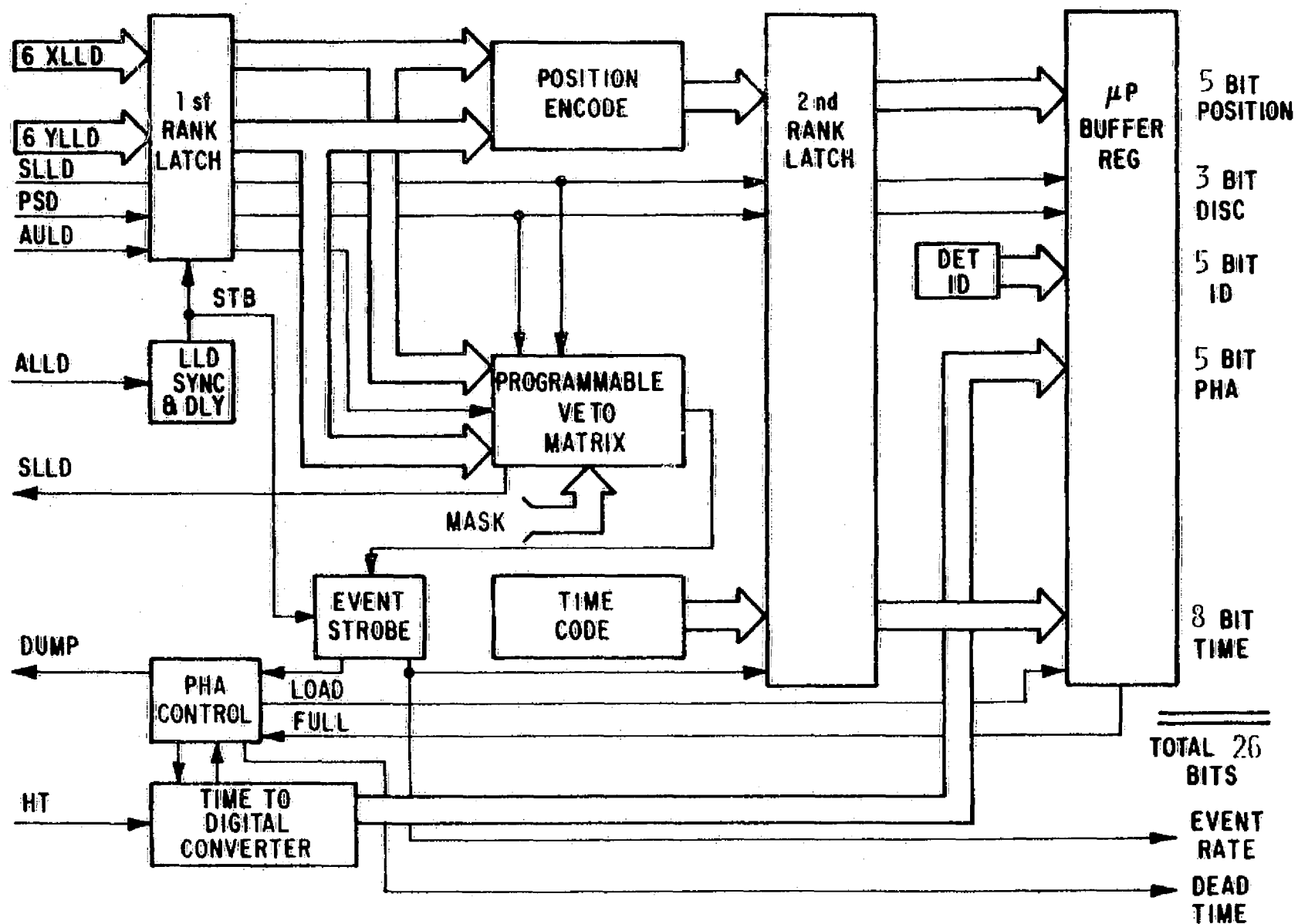


Figure 4.2-5b HXII Front-End Electronics

4.3 ELECTRONICS INTERFACES

The primary electronics interfaces for the Hard X-Ray Imaging Instrument (HXII) consist of the interface between the front-end electronics (discussed in Section 4.2) and the microprocessor system as well as the interface between the microprocessor system and the Spacelab Command and Data Management Subsystem (CDMS). In addition to the front-end electronics there are other instrument functions which are controlled by and must therefore interface with the microprocessor system. The subsequent paragraphs will be devoted to a discussion of these internal and external electronics interfaces that are shown in Figure 4.3-1.

4.3.1 Internal Electronics Interfaces

The basic internal electronics interface within the HXII is between the imaging detectors and the microprocessors which control their operation and prepare the data for transmission. As shown in Figure 4.3-1, a total of four microprocessors will be used for interfacing with the 15 argon and 15 xenon detectors. Two of the microprocessors will be used for event binning functions and a third will be utilized as a tagged-event processor. Present plans are to utilize a 32-bit word to tag each event with the breakdown of the 32 bits as follows:

- Pixel Identification - 5 bits
- Frame Identification - 5 bits
- Pulse-Height Analysis - 5 bits
- Time - 8 bits
- Flags - 3 bits
- Unassigned - 6 bits

The fourth microprocessor in this group will be used as a binning priority processor to be utilized during period of high activity. Although the goal of the HXII is to transmit as much

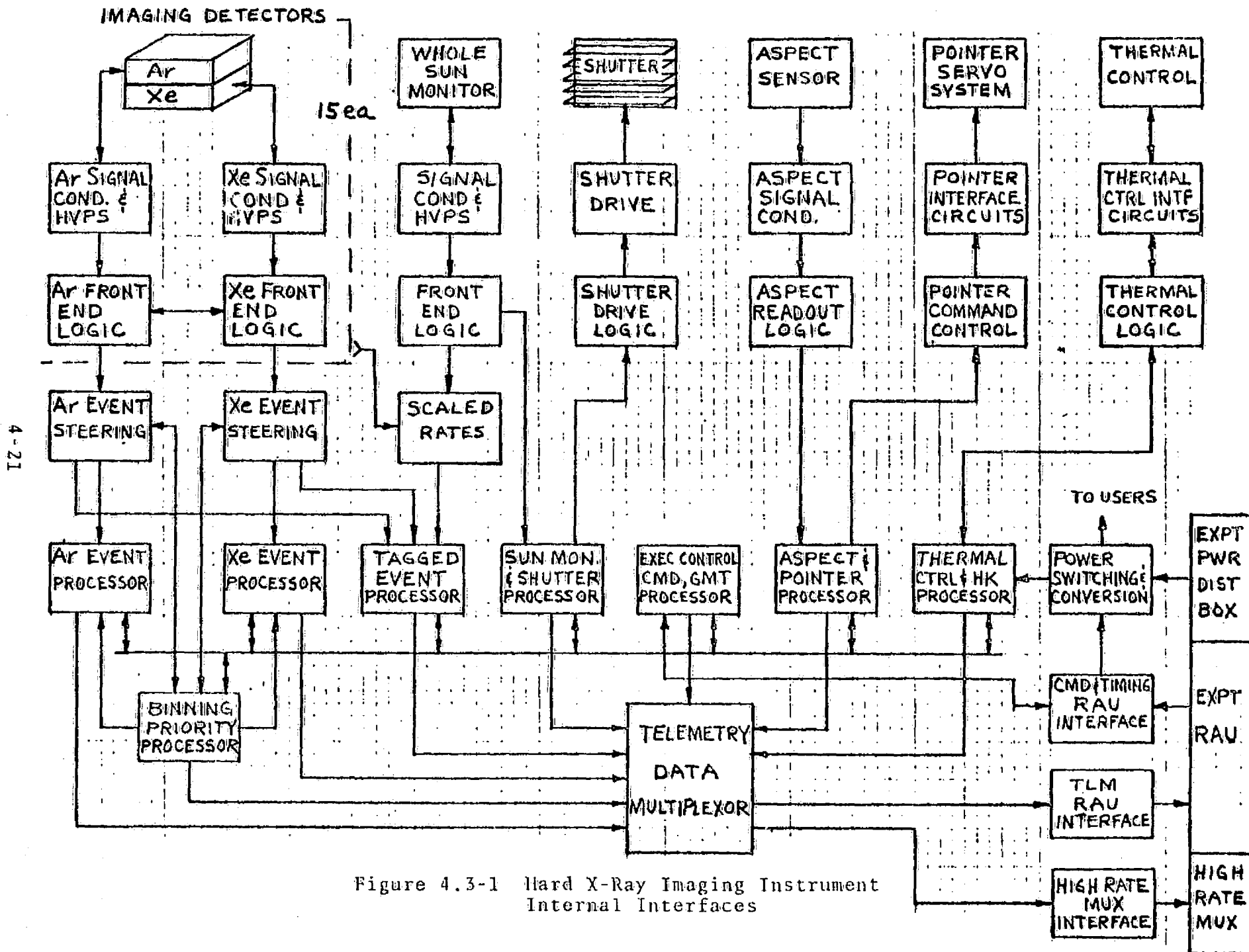


Figure 4.3-1 Hard X-Ray Imaging Instrument Internal Interfaces

fully tagged data as possible, the expected count rates during periods of high activity will produce bit rates which the system would not be able to handle. The argon and xenon detectors would generate the following bit rates:

- Argon
20,000 events/sec x 32 bits/event x 15 detectors =
 9.6×10^6 Bps
 - Xenon
2,000 events/sec x 32 bits/event x 15 detectors =
 1.0×10^6 Bps
- Worst case total bit rate =
 10.6×10^6 Bps

In order to avoid data rates of this magnitude, the binning priority processor will isolate the most active channels by identifying the high frequency events tags, both by energy and by pixel. The most active channels will be diverted from tagged data to bins which will be output at 0.2 second intervals. Each time the bins are read out, the processor will update the channels being binned based on current activity levels.

As indicated in Figure 4.3-1 the other four microprocessors in the system will serve the following functions:

- Housekeeping and Thermal Control
- Full Sun Monitor and Shutter Control
- Aspect and Pointer Control
- Executive Control, Command and GMT

All eight of the microprocessors will be tied together on a common bus and the executive control processor will direct the efforts of the total system.

4.3.2 External Electronics Interfaces

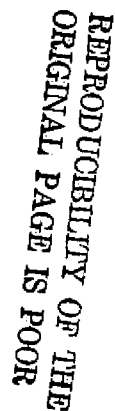
The external electronics interfaces for the HXII consist of the electrical interfaces with the Spacelab electrical power and distribution subsystem (EPDS) as well as the command and data interface with the Spacelab CDMS.

The electrical interface will be a direct link through a Spacelab provided experiment power distribution box. The power which will be available through this interface will be 28 VDC and 115/120 VAC at 400 Hz.

The interfaces to the Spacelab CDMS are shown in Figure 4.3-2. The Spacelab experiment input/output unit will control the distribution of on-board and ground originated command information as well as timing and Orbiter state vector data to the HXII. The information will be transmitted over the experiment data bus and through the remote acquisition unit (RAU) to the instrument.

The RAU, the capabilities of which are shown in Figure 4.3-3, will also serve as the interface for control data which will be transferred to the experiment input/output unit for formatting in the experiment computer and output to the display unit at the payload specialist station. The data rate for this control data is currently estimated at between 1.5 KBps and 5 KBps. With this data rate and the number of commands envisioned for the HXII it is currently felt that a total experiment RAU would not be required and could therefore be shared with another experiment if necessary. The current estimate of the services to be used by the HXII is shown in Figure 4.3-4.

The high rate scientific data from the HXII, which will be in the 200 KBps to 500 KBps range, will be transferred directly to the Spacelab high-rate multiplexer. The transfer will take place over a hardwire channel which is capable of accepting an input with a bit rate of from 62.5 KBps to 2 MBps. The low-rate control



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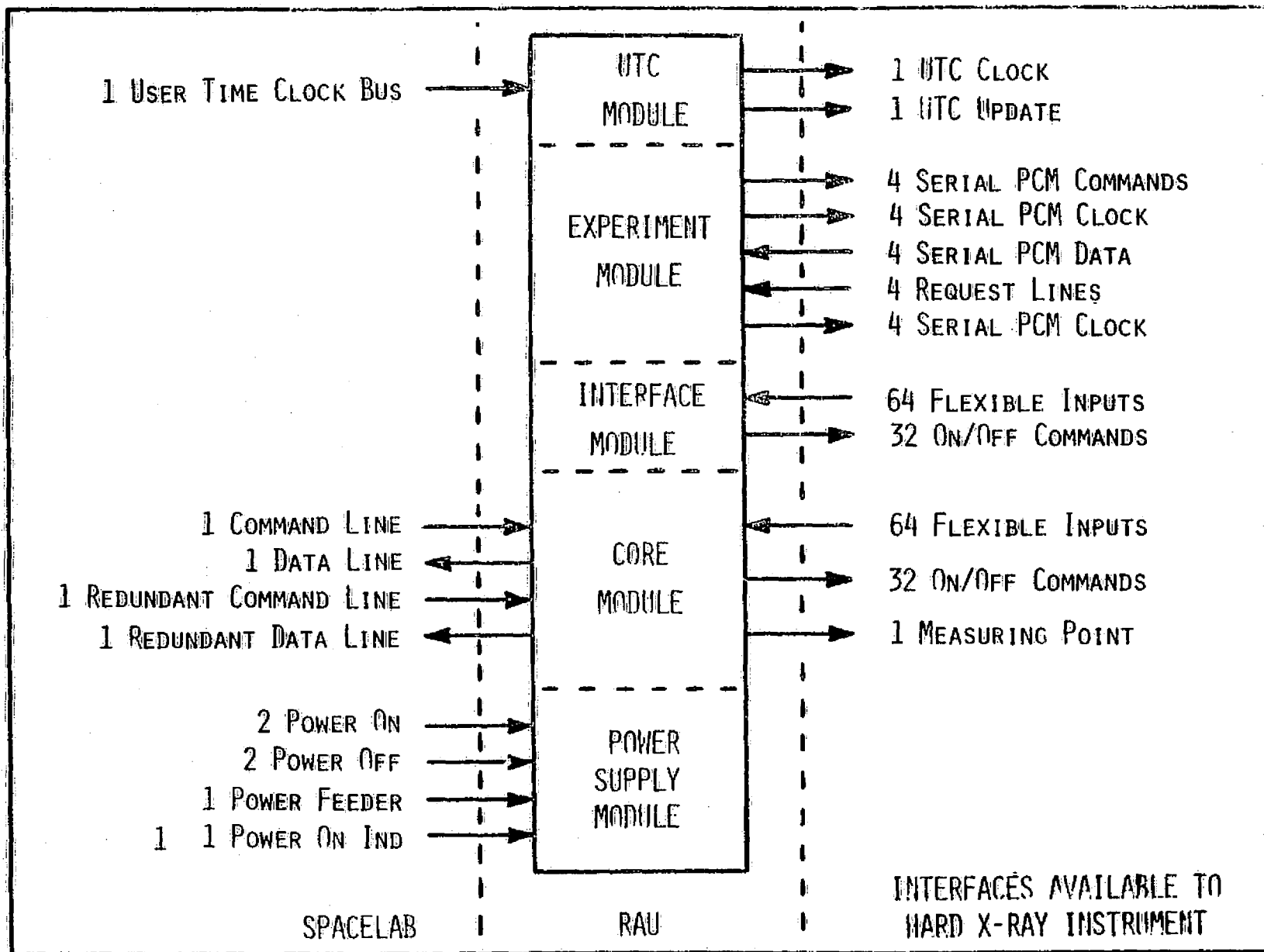


Figure 4.3-3 Spacelab Remote Acquisition Unit (RAU) Capabilities

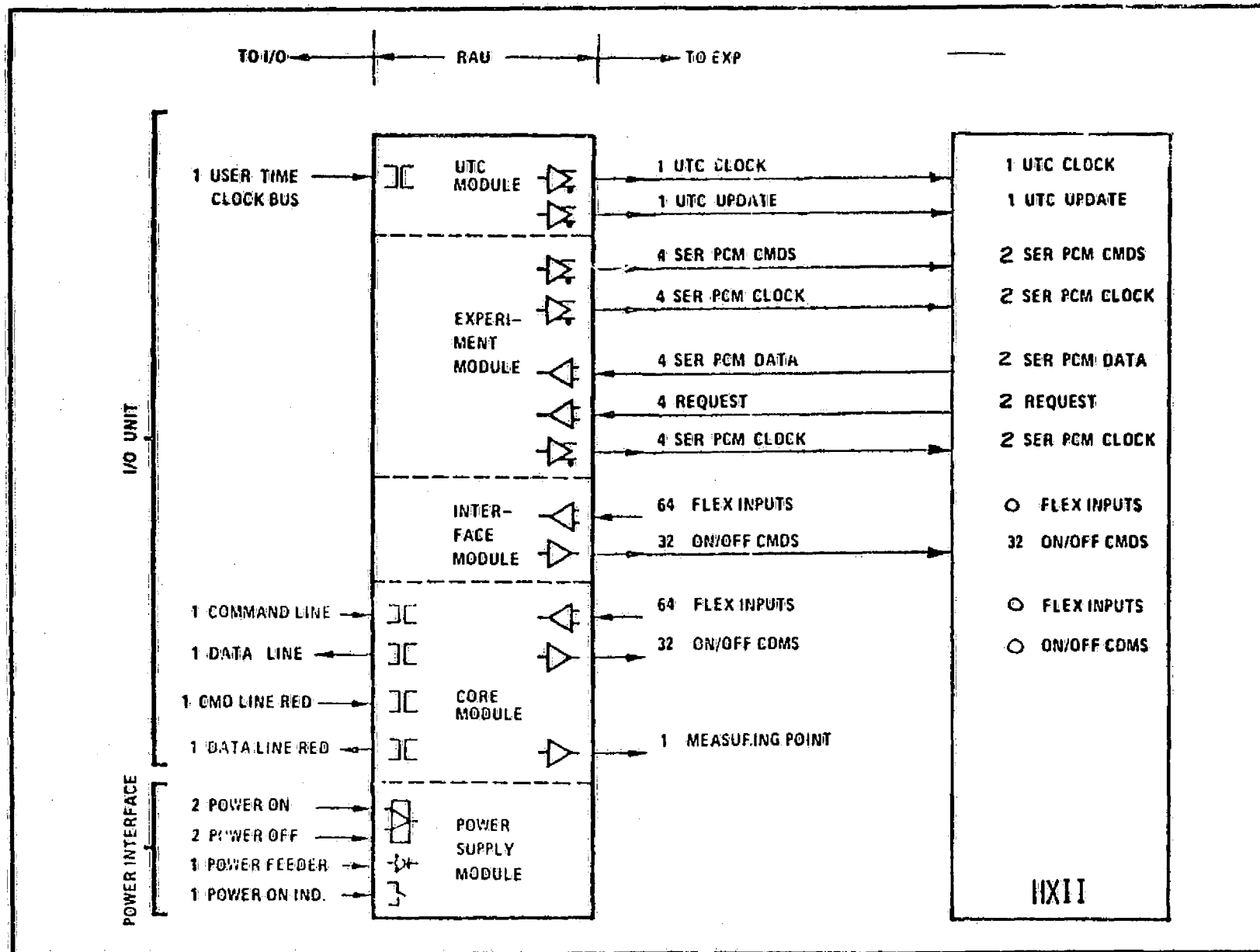


Figure 4.3-4 Hard X-Ray Imaging Instrument RAU Utilization

data (1.5 Kbps to 5 Kbps) discussed above will also be transferred to the high-rate multiplexer by the experiment input/output unit for multiplexing back into the data stream and transmission to the ground. These two interfaces are shown in Figure 4.3-5.

If the Orbiter is in TDRSS coverage the high-rate scientific data will be transferred directly to the Ku-Band signal processor for relay to the ground via the TDRSS in near realtime. During periods when the TDRSS is not available for use by Orbiter, the high-rate data will be recorded on the Spacelab high-rate digital recorder. When the TDRSS again becomes available for Orbiter support, the stored data from the high-rate digital recorder will be interleaved into the realtime data stream on the Ku-Band downlink.

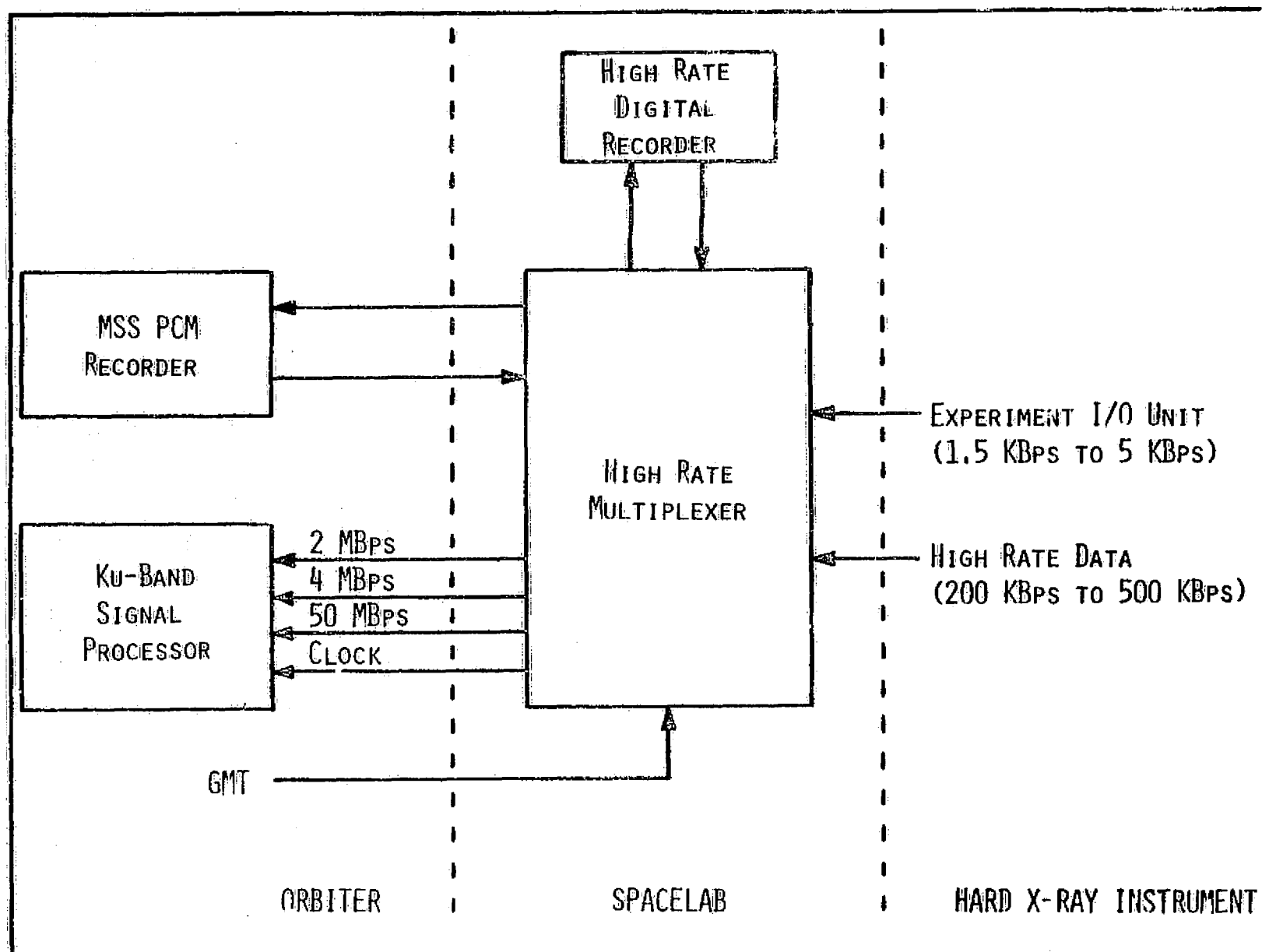


Figure 4.3-5 Hard X-Ray Imaging Instrument/High Rate Multiplexer Interface

4.3.3 Power Requirements

The breakdown of the power requirements for the Hard X-Ray Imaging Instrument (HXII), excluding the pointing control system, is shown in Table 4.3-1. This power estimate was established utilizing the power required by the front-end electronics, microprocessors, interface circuits, special controllers, shutter driver and the thermal control system.

The current estimate for the signal conditioning portion of the front-end electronics is 101 watts as shown in Table 4.3-2. An additional 89 watts has been added to this figure to cover the electronics required to interface the signal conditioning for a total of 190 watts for the front-end electronics.

Current estimates are that a total of eight microprocessors will be required to support the HXII. Four of these microprocessors will be utilized as proportional counter handlers and the other four will serve the following functions:

- Housekeeping and Thermal Control
- Full Sun Monitor and Shutter Control
- Aspect and Pointer Control
- Executive Control, Command and GMT

Assuming a power figure of five watts per microprocessor and a low voltage power supply overhead at 70% efficiency, the total power required for the microprocessors is 57 watts.

For the purpose of establishing the power requirement for the HXII, the total power required for the thermal control system is estimated at 200 watts. Although further thermal analysis may require an update of this estimate, it is felt to be a representative number based on past experience.

ITEM	POWER (WATTS)
• FRONT-END ELECTRONICS	190
• MICROPROCESSORS	57
• INTERFACE CIRCUITS AND SPECIAL CONTROLLERS	43
• SHUTTER DRIVE	30
• THERMAL CONTROL	200
• TOTAL POWER CONSUMPTION (EXCLUDING POINTER SYSTEM)	520

Table 4.3.3-1 Hard X-Ray Imaging Instrument Total
Power Consumption

ITEM	POWER (WATTS)
• CHARGE SENSITIVE PREAMPLIFIERS	10.0
• VOLTAGE AMPLIFIERS	10.0
• SHAPING AMPLIFIERS	10.0
• DISCRIMINATORS	11.5
• PULSE-HEIGHT ANALYZERS	8.4
• PULSE-SHAPE ANALYZERS	5.6
• HIGH VOLTAGE POWER SUPPLIES	15.4
• LVPS OVERHEAD @ 70% EFFICIENCY	30.4
• TOTAL POWER CONSUMPTION	101.3

Table 4.3.3-2 Signal Conditioning Power Estimate

The power required for the shutter driver is estimated at 30 watts, and the interface circuits and special controller will probably consume somewhere around 43 watts.

When all of these figures are summed, the total power requirement is 520 watts as shown in Table 4.3-1. For the purpose of this study, this number has been rounded to 500 watts for the total HXII power requirement.

CONCLUSIONS AND RECOMMENDATIONS

- The HXII is compatible with a balanced pointing system such as the large option SIPS.
- A truss-like structure supporting both the grids and proportional counters, and with a dedicated SIPS-type gimbal frame is feasible for HXII, but it cannot be aligned or checked in the horizontal position.
- A single, full size structure most nearly meets the useful area criteria.
- The quadrant size structure most nearly meets an "optical bench" stiffness, but sacrifices useful area and weight (120 kg vs 84). It permits horizontal alignment.
- The Airy mount arrangement should be evaluated at least to the extent of determining the maximum useful area. If it is suitable for this criterion, it should be evaluated further because it could be aligned in a horizontal position.
- Detailed thermal and structural analysis should be completed before a full design effort is initiated.
- A single gas chamber for four collimators, and with four detectors, is feasible. This approach maximizes usable viewing area.
- A parylene or mylar window would greatly reduce the cost and fabrication problems associated with a 2- to 5 mil beryllium window.

- Glass-bonded mica ceramic is suitable for the wire frames if it can be metal plated for welding the wires. If not, alumina ceramic can be used.
- A finite-element model of the egg crate should be developed to determine influence coefficients, stresses, and deflections to determine if it can support thinner housing side walls.

The tradeoff analysis for the optimum proportional counter readout configuration results in a flexible simple scheme for constructing the counters. Several electronic implementations for the readout of position, energy, pulse shape and anticoincidence data remain possible without significantly impacting the design of the counter. It is proposed to make all wire frames square and of the same dimensions, using stainless steel wire of about 1 mil for anodes and cathodes. This makes all wire frames interchangeable. Direct readout (6 x 6), resistive wire readout of anodes and/or cathodes as well as combinations of these are feasible. Final decisions on the readout method to be adopted can be based on economic/cost/performance tradeoff of the electronics.

Should it be desirable to provide one or more collimators with a coded aperture (random hole pattern for example) then the two-dimensional RC-line method can be used without much penalty.

REFERENCES

1. J.L. Alberi and V. Radeka, "Position Sensing By Charge Division", IEEE Trans. Nucl. Sci. NS-23, No. 1, 251-258, 1976.
2. C.J. Borkowski and M.K. Kopp, "Some Applications and Properties of One and Two-Dimensional Position-Sensitive Proportional Counters", IEEE Trans. Nucl. Sci., NS-17, 340, 1970.
3. C.J. Borkowski and M.K. Kopp, "Design And Properties of Position-Sensitive Proportional Counters Using Resistance-Capacitance Position Encoding", Rev. Sci. Instr. Vol. 46, No. 8 951-962, August 1975, (1975a)
4. A. Breskin, G. Charpak, B. Gabioud, F. Sauli, N. Trautner, W. Duinker, and G. Schultz, "Further Results on the Operation of High-Accuracy Drift Chambers Nucl. Instr. and Methods 119, 9-28, 1974.
5. A. Breskin, G. Charpak, F. Sauli, M. Atkinson and G. Schultz, "Recent Observations and Measurements With High-Accuracy Drift Chambers", Nucl. Instr. and Methods 124, 189-214, 1975.
6. G. Charpak, F. Sauli and W. Duinker, "High-Accuracy Drift Chambers And Their Use In Strong Magnetic Fields", Nucl. Instr. and Methods 108, 413-426, 1973.
7. J.G. Emming and J.R. Gilland, "A Multiwire Proportional Counter With Integral Readout Delay Line", IEEE Trans. Nucl. Sci., NS-20, 145, 1973.
8. E.R. Flynn, S. Orbesen, Nelson Stein, H.A. Thiessen, D.M. Lee and S.E. Sobottka, "Application of the Helical Cathode Proportional Chamber to Magnetic Spectrographs For Nuclear Reaction Studies", Nucl. Instr. and Methods 111, 67-76, 1973.
9. J.R. Gilland and J.G. Emming, "A Multiwire Proportional Counter With Integral Readout Delay Line", Nucl. Instr. and Methods 104, 241-243, 1972.
10. R. Grove, I. Ko, B. Leskovar and V. Perez-Mendez, "Phase Compensated Electromagnetic Delay Lines For Wire Chamber Readout", Nucl. Instr. and Methods 99, 381-385, 1972.
11. A.P. Jeavons, N. Ford, B. Lindberg, C. Parkman, and Z. Hajduk, "Two-Dimensional Proportional Chamber Readout Using Digital Techniques", IEEE Trans. Nucl. Sci., NS-23, No. 1, 259-263, February 1976.

12. D.M. Lee and S.E. Sobottka, "A Bifilar Helical Multiwire Proportional Chamber For Position Sensitive Detection of Minimum Ionizing Particles", Nucl. Instr. and Methods 104, 179-188, 1972.
13. V. Radeka, "Signal, Noise and Resolution in Position-Sensitive Detectors", IEEE Trans. Nucl. Sci., NS-21, No. 1, 51-64, 1974.
14. C. J. Borkowski, M. K. Kopp, and J. A. Harter, "Line-Scanning Proportional Counter Camera", IEEE Trans. Nucl. Science, Vol. NS-22, No. 2, April 1975 (1975b)

APPENDIX

Proportional Counter Gas Chamber Housing.

The housing consists of flat plates and the internal pressure will bend the plates. Potentially this will:

- 1) overstress the beryllium windows
- 2) cause "O" ring leakage

Also, the housing thickness T is nonactive area and should be minimized.

The formula for deflection of a uniformly loaded, end supported beam is:

$$y = \frac{5 W l^3}{384 E I}$$

where

W = total load

$$= p h l$$

and h = height of chamber.

$$\text{Then } y = \frac{5 p h l^4}{384 E I}$$

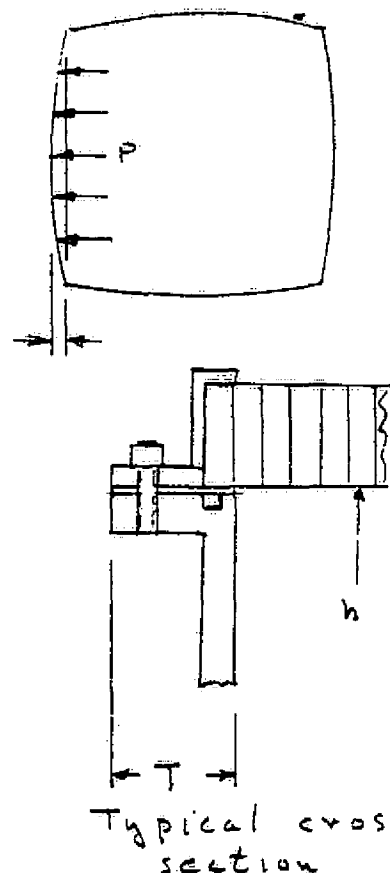
Let $P = 2 \text{ atmos} = 30 \text{ psi}$

$h = 8 \text{ inches}$

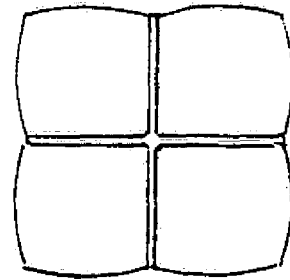
$l = 17.5 \text{ inches}$

A 1.0 inch thick aluminum plate would deflect .042 inches at the center.

Obviously a center member is required, reducing the chamber to 4 quadrants. This area is non-active area anyway due to the collimator grid frames.



There will still be some deflection at the midpoints and it will be dependent on the area of the center members and I of the frame.



For the center members;

$$y = \frac{FL}{AE}, \text{ where } L = \frac{1}{2}l$$

For the frame;

$$y = \frac{5WL^3}{384EI} - \frac{FL^3}{48EI}$$

Then, since the deflections must be equal,

$$\frac{FL}{AE} = \frac{5WL^3}{384EI} - \frac{FL^3}{48EI}$$

$$F = \frac{5WL^3A}{384\left(IL + \frac{AL^3}{48}\right)}$$

Let $A = \frac{3}{8} \times 8$ plate, $A = 3 \text{ in}^2$
 $l = 10 \text{ in}$
 $W = 4200 \text{ lbs}$
 $I = 1281 \text{ in}^4$
 $L = 9$

Then $F = 2606.91$

$$y = 7.82 \times 10^{-5} \text{ (from either side of the above equation)}$$

This appears adequate. However, the wire frames will be attached to each corner of a quadrant, and deflection at the midpoints will distort the frames and change wire tension.

Next, a suitable cross section for the housing

frame must be determined such that deflections are not harmful.

Again, $y = \frac{5WL^3}{384EI}$ is used, where

$$L = 8.75 \text{ inches}$$

$$W = 30(8)(8.75) = 2100 \text{ lbs}$$

For a simple flat plate: $I = \frac{bh^3}{12}$

h	b	I	y
.50	8	.083	.022
.75	8	.281	.0065
1.00	8	.667	.0027

The beryllium window will have a limit to its stretch.

$$\Delta L = \frac{SL}{E} \quad \text{where } S = \text{stress} = 12,500 \text{ psi}$$

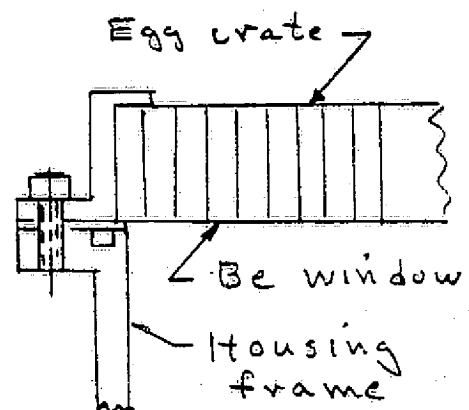
$$L = 8 \text{ inches}$$

$$E = 42 \times 10^4 \text{ psi}$$

$$\Delta L = .0024 \text{ at } 50\% \text{ yield strength.}$$

It becomes obvious that either a rather thick housing frame is required, or some other support is required.

The egg crate window support/collimator can be used as tension members if they are brazed to the cover frame. Although presumably only .010 in thick, there are many of them.



Unfortunately, utilizing the egg crate as tension members does not lend itself to quick numerical analysis, since each strip is stretched a different amount. A computer model is needed to determine the influence coefficients and determine stress and deflections. Time and money does not allow for that during this study.

It appears that a frame in the form of a channel section, with .63 inch flanges may be a feasible frame candidate. The egg crate will be used as tension members.

If, after detail analysis this turns out not to be true, the fallback options are:

- deeper section frames
- increased modulus of elasticity (stainless steel).

Tension on Anode & Cathode wires.

The minimum tension required on the anode wires to prevent oscillation due to the electrical forces is*:

$$T = \frac{q^2 L^2}{s^2} \quad \text{where } T = \text{force in dynes}$$

q = charge per unit length in Stat Coulomb

L = length of the wires

s = anode wire spacing.

The charge per unit length $q = \frac{V}{2k}$

where V is in statvolts

and k is a characteristic of the multiwire proportional counter defined as:

$$k = \ln \left[\sinh \left(\frac{\pi D}{s} \right) / \sinh \left(\frac{\pi r}{s} \right) \right]$$

r = radius of wire, D = spacing between anode and cathode planes

$$V = 4000 \text{ volts} (.00336) = 13.44 \text{ statvolts}$$

$$D = 1 \text{ cm}$$

$$r = 1.27 \times 10^{-3} \text{ cm}$$

$$L = 19 \text{ cm}$$

$$s = .25 \text{ cm}$$

$$\text{Then } k = 16.0$$

$$q = .42$$

$$T = 1000 \text{ dynes} = 1.02 \text{ grams} = 2.27 \times 10^{-3} \text{ lbs}$$

For a 1 mil stainless steel wire, this force stresses the wire to 2890 psi. However it does not take into account differential contraction/expansion at temperature extremes.

* P. Schilly et al; Nucl Instr and Methods 91, 1971, 221.

304 stainless steel has the following properties:

$$\begin{aligned} \rho &= .29 \text{ lbs/in}^3 \\ \alpha &= 9.6 \times 10^{-6} / ^\circ\text{F} \\ E &= 28 \times 10^6 \text{ psi} \\ S_y &= 35,000 \text{ psi} \end{aligned}$$

Mycalex, a glass bonded mica ceramoplastic recommended for the wire frames has the following properties:

$$\begin{aligned} \rho &= .108 \text{ lbs/in}^3 \\ \alpha &= 5.8 \times 10^{-6} / ^\circ\text{F} \\ E &= 11 \times 10^6 \text{ psi} \\ S_y &= 15,000 \text{ psi} \end{aligned}$$

The temperature range is 0 to 50°C (32 to 122°F)

Assume the wires are welded to the frames at 72°F.

$$\begin{aligned} \Delta T &= 50^\circ\text{F} \text{ hot} \\ &= 70^\circ\text{F} \text{ cold} \end{aligned}$$

For a preload of 15,000 psi,

$$F = SA = 15000 \left(\frac{\pi}{4} \times 10^{-6} \right) = 1.18 \times 10^{-2} \text{ lbs (5.4 gr)}$$

The deflection in one G is .00015 inches.

At maximum (hot) temperature, the wire is stretched an additional amount

$$\begin{aligned} \Delta L &= L (\alpha_s - \alpha_m) (50) = 7.75 (3.8) (50) \times 10^{-6} \\ &= 1.47 \times 10^{-3} \text{ in} \end{aligned}$$

$$\Delta \text{ stress} = \frac{\Delta L E}{L} = 5300 \text{ psi}$$

Total stress will be 20,300 psi, which is acceptable.

The cathode wires could be 3 mil copper or stainless steel depending on the readout method selected. The tension for stainless steel will be analyzed as this will give worst case (maximum) loading on the frames.

Using the same calculations as before for minimum stability tension:

$$K = 17.2$$

$$g = .10$$

$$T = 58 \text{ dynes} = 5.7 \times 10^{-3} \text{ grams}$$

Again using a preload of 15,000 psi,

$$F = .106 \text{ lbs} \quad (48 \text{ grams})$$

For a 19.7 cm frame, with 25 cm wire spacing, 78 wires will be required.

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Support for .005 in thick beryllium window at 2 atmospheres of pressure in proportional counter.

For a flat, square plate, all edges fixed, uniform load "w" over entire surface,*

$$S = \frac{.308 w a^2}{t^2} \text{ at center of edge}$$

$$y = \frac{.0138 w a^4}{E t^3}$$

For beryllium, $S_y = 25,000 \text{ psi}$

$$E = 42 \times 10^6 \text{ psi}$$

Based on stress with a safety factor of 2:

$$a = \sqrt{\frac{12,500 (.005)^2}{.308 (30)}} = .184 \text{ inches (4.7 mm)}$$

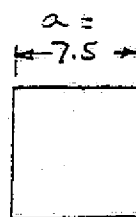
$$y = 9.0 \times 10^{-5} \text{ in}$$

The deflection is small enough so membrane forces do not enter. If one uses the edge supported case, "a" is larger but the deflection is too large.

To find eggcrate depth, find equivalent for a flat plate, for a deflection limit. $y = .005$

Using supported edge case,

$$y = \frac{0437 w a^4 (m^2 - 1)}{m^2 E t^3}$$



* Rourke, Formulas for Stress & Strain, 4th Edition, Table X, case 34, p. 225

$$t = \left[\frac{.0487 \omega a^4 (m^2 - 1)}{m^2 E y} \right]^{1/3}$$

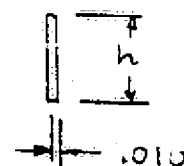
$$t = \left[\frac{.0487 (30)(7.5)^4 (9-1)}{9 (42)(.005) \times 10^6} \right]^{1/3} = .27 \text{ inches}$$

$$I = \frac{bh^3}{12} \quad \text{where } h = .27, \quad b = .184$$

$$I = 3.0 \times 10^{-4}$$

For the eggcrate, use $b = .010$ and find h for equivalent I .

$$h = \left(\frac{12I}{b} \right)^{1/3} = .71 \text{ in } (1.8 \text{ cm})$$



The eggcrate will have .010 inch aluminum walls, a cell size of .184 inches, and be a minimum of .71 inches thick.

This will be 10.9 % opaque before grading.

Can it be graded?

Using the same equations and varying t :

t	a	y	opacity
.006	.227	4.6×10^{-5}	9 %
.008	.294	5.5×10^{-4}	6.8 %
.010	.368	7.6×10^{-4}	5.4 %

SAFETY REQUIREMENTS.

Although 2 atmospheres (differential) does not seem like much pressure, there is a load of 7680 pounds on the windows, and the chamber is a pressure vessel. NASA requires a proof test at 2x operating pressure and a design (burst) pressure of 4x operating pressure - unless fracture mechanics analysis is performed.

The grains in beryllium are typically 25 microns in size, and when worked, the surface has microscopic cracks 25 to 50 microns deep. The manufacturers will not guarantee 2 mil foil (50 microns) to be vacuum tight because of these cracks. Since beryllium is a brittle material it lends itself to the classical approach of fracture mechanics. It has been assumed here that fracture mechanics analysis will be performed and a safety factor of 2 to 2.5 will be adequate.

Proportional Counter Wire Frame Sizing

The anode wire tension load is 1.18×10^{-2} pounds per wire. 78 wires are required per frame. The frame is a beam uniformly loaded.

$$M = \frac{1}{8} W L = \text{moment load.}$$

$$= \frac{1}{8} (78)(1.18)(7.75) \times 10^{-2}$$

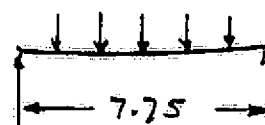
$$= .89 \text{ in. lbs.}$$

$$S = \frac{M c}{I} = \text{stress in frame.}$$

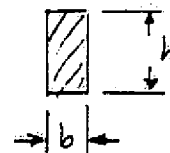
For Mycalex, let $S = 1000 \text{ psi}$

$$\frac{I}{c} = \frac{M}{S} = \frac{.89}{1000} = 8.9 \times 10^{-4}$$

$$\frac{I}{c} = \frac{b h^2}{6}$$



Loading



Frame
Section

Need sufficient b for screw fasteners

$$h = 1 \text{ cm} = .40 \text{ in}$$

$$\text{let } b = .30 \text{ in}$$

$$\frac{I}{c} = \frac{.3 (.4)^2}{6} = 8.0 \times 10^{-3}$$

Deflection :

$$y = \frac{5 W L^3}{384 E I} = \frac{5 (.92)(7.75)^3}{384 (11)(8) \times 10^3} = 6.3 \times 10^{-5} \text{ in.}$$

This appears satisfactory.

The cathode wires have a tension load of .106 pounds per wire, and there are $78(2) = 156$ wires for 2 planes continuously wrapped. This is reacted on 2 frames pinned together. The frame is a beam, uniformly loaded by the wires.

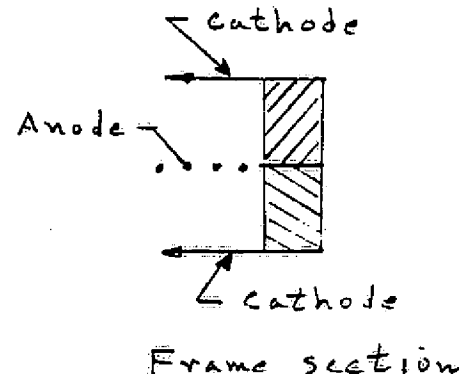
$$M = 16 \text{ in lbs}$$

$$S = \frac{M}{I/c}$$

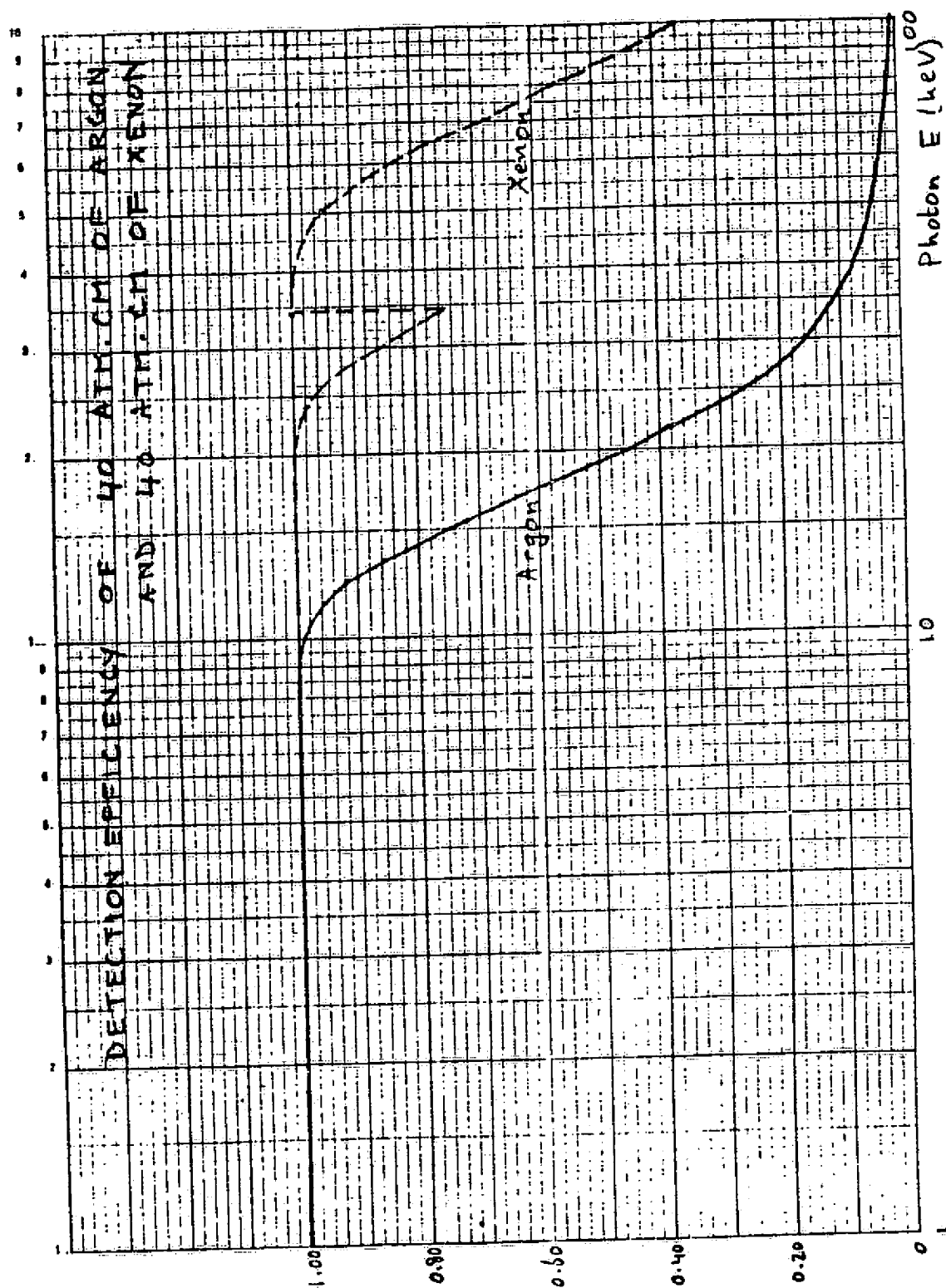
$$\frac{I}{c} = 2(8) \times 10^{-3} = 1.6 \times 10^{-2}$$

$$S = \frac{16}{1.6 \times 10^{-2}} = 1000 \text{ psi.}$$

This appears satisfactory.



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SECTION V

MANAGEMENT CONCEPTS

FOR A

HARD X-RAY IMAGING INSTRUMENT

V. MANAGEMENT CONCEPTS

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A. Management as a NASA Facility

(1) Introduction.

We present here a plan for the development and operation of the HX11 as a facility-class instrument. This includes the Phase B design study, hardware construction, operations, data reduction and analysis. The present Facility Definition Team (FDT) forms a core group for the various phases. Hardware and operation management is through NASA centers with scientific participation broadened in stages through appropriate Announcements of Opportunity. Figure V-1 summarizes the plan.

This document is the outcome of a discussion at the 28-29 September 1975 FDT Meeting in Berkeley, followed by a draft plan dated 12 December 1975, written by the Team Leader. This was extensively discussed at the 15-16 December meeting in Boulder jointly by the FDT and NASA representatives from the GSFC Astronomy Shuttle Payloads (ASP) Project.

(2) Assumptions.

(a) The present FDT, formed in response to an Announcement of Opportunity (AO), contains a majority, but not all, of the members of the scientific community who have direct interest in the instrumentation, observations, or interpretation of data associated with a solar hard X-ray imaging facility.

(b) The present FDT, in conjunction with various engineering groups, has completed "phase A" definition period.

(c) The facility, because of its size, complexity and uniqueness cannot be the domain of a single Principal Investigator and his institution.

(d) The construction, management and operation of the facility will be the responsibility of a NASA Center, such as the GSFC.

(e) In order to maintain viability it is necessary to have strong scientific input and control at all stages of design, construction, operation, and data management.

(3) Role of FDT.

In order to accomplish the scientific objectives under the above assumptions, we must conceive a new management approach. Because of the particular interest and expertise of the present membership of the FDT, we assume it can form a core group with a central, but evolutionary, role in the various phases of the facility development and operation.

In addition to the overall interest in astrophysical X-ray phenomena, the members of the present FDT or their organizations have particular expertise in the following areas:

Collimators:

Blake, Garmire, van Beek

Detectors:	Garmire, Peterson, van Beek
Electronic Systems:	Garmire, Peterson, van Beek
Auxiliary and Monitor Instruments:	Lin, Hudson, Peterson, Svestka
Systems Engineering and Management:	Peterson, Svestka
Operations:	Crannell, Garmire, Hudson, Lin, Svestka
Data Management and Reduction:	Lin, Peterson
Data Analysis and Synthesis:	Blake, Hudson, Lin, Svestka

We envision a plan whereby the present FDT evolves into a consortium, responsible for guiding the development and operation of the facility. At different stages, various members, depending on the expertise required, will have more or less key responsibilities. Furthermore, the scientific participation is expanded at various stages through AO's, such as for participation in the development phase, or the formation of a Users' Group during operations. Proposals in response to the AO's are evaluated by NASA, with input from the central consortium, or its representative.

(4) Management Plan:

(a) Phase B design. This design study is the next step after the work of the presently defined FDT. We suggest this be either conducted through UCSD, under contract to GSFC, as is the FDT at present, or directly through GSFC, with the present Team remaining intact, but having major input to the study as consultants. This group would submit to NASA a proposal, based on the present Definition Study, and would function as a consortium, chaired by a Team Leader, who would have somewhat the role of the classical PI.

At this time a strong Study Scientist from within the NASA center would be appointed. It is assumed this individual would continue on the project through phase C/D and operations and have personal interest in the results.

The major portion of the work would be done in conjunction with an Individual Contractor, with various members of the consortium being responsible for particular subsystems or areas. The Team would have considerable input and interaction through a series of meetings and reviews.

The output of the Phase B study would be available to all members of the scientific and industrial community.

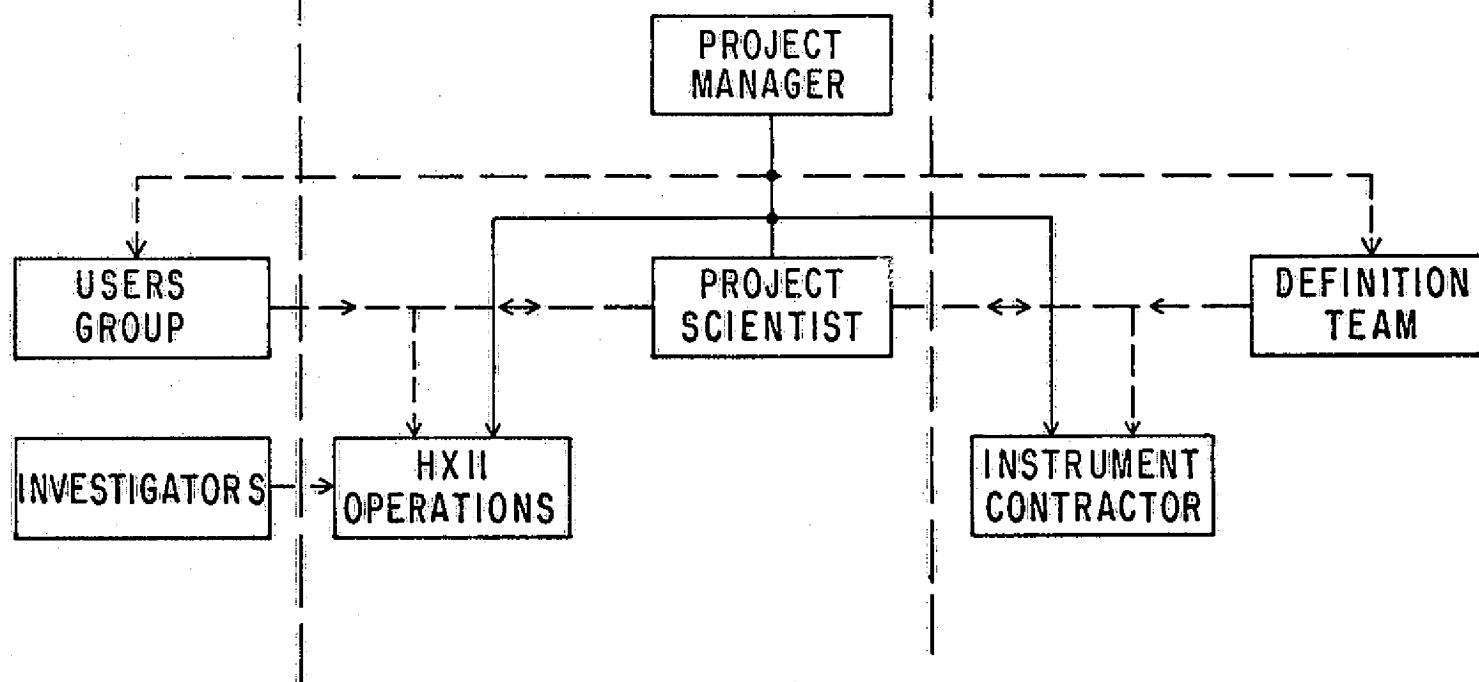


Figure V-1

(b) Development and construction, Phase C/D. This will be accomplished by a contractor selected competitively, in response to an RFQ. At this time, the Team role becomes consulting and advisory, and functions as a collective P.I. through the Project Scientist. Management responsibility will be assumed by GSFC, which requires a strong Project Manager and Project Scientist. The latter participates in the daily technical decisions, and is responsible to the scientific Team. Ideally this person should be appointed or at least approved by the Team, since he (or she) bears the key responsibility for the goals and objectives defined by the team to be implemented as meaningful hardware.

Members of the present FDT may also have a hardware role, as determined during phase B. For example, certain items such as collimator grids or detectors may be best constructed at a member's laboratory where the expertise exists.

In order that the scientific group not become ingrown, sometime near the start of the phase C/D, an AO may be issued for participation in this phase, and in the planning for the early flights. Added participation would be on the basis of being able to contribute significantly to a particular task, provide needed expertise, or supply uniquely a portion of the hardware. It would be assumed that the group at this time would have contributed sufficiently to the facility to have primary access to the results of the early flights.

During this phase, the role of the various members of the team will involve oversight and outside review of various systems and subsystems, and liaison and monitoring function. The GSFC Project Manager and Project Scientist are the principal contacts. We envision considerable involvement by the Team in the various design and management reviews, and as a minimum, consultation on Class I level change-control items.

(c) Operations and Early Flight. During the early stages of the instrument construction, planning for flights must commence. This requires two distinct, but coupled efforts:

(i) An operations group at GSFC, reporting to the Project Scientist and Manager, must be formed. This group must consist of a small number of technical and software specialists who are responsible, with contractor assistance, for the detailed checkout, integration, operation, refurbishment and updating of the facility from flight-to-flight. This group also acts as a liaison between the various NASA Centers responsible for the different stages of the Shuttle Integration, checkout launch and operations, and data retrieval. These people have personal involvement with the facility, a long term commitment, work directly with the user scientists, and have the same sense of dedication and empathy that a Principal Investigator and technical staff as a university maintain.

(ii) A scientific Users' Group, formed initially from a subset of the Phase C/D team and chaired by one of its members. They are responsible for planning the calibration, observation sequence,

Operations Control Center interactions, coordination with other shuttle and ground based activities, and planning data reduction and analysis procedures. This group can also indicate changes in procedure, and updates in software or hardware which will increase the scientific return of the facility. As the Phase C/D proceeds, the Users' Group will perform an increasingly dominant and essential role in the operation of the facility, as the hardware, construction and initial tests of the instrument are completed. This group will also be responsible for distribution of the data from the early flights in some equitable and democratic manner, recognizing the particular scientific interests of the team, individual, or group.

(d) Follow-on flights. As the facility nears completion, and the first flight is imminent, an AO for participation in follow-on opportunities should be issued. There could be two kinds of participation: as a member of the Users' Group, which is responsible for the scientific operation and observing schedule of the facility and has major access to the data, or as a guest investigator, who proposes specific observations, studies based on available data synthesized in a unique manner, or supporting and collaborative observations using other shuttle or ground-based instruments.

The Users' Group could be chaired by a scientist outside the project who serves a term (3 years?) and is a consultant to the Project Scientist. The GSFC Project Scientist, who is in effect the Scientific Director of the facility, is an important and permanent member of the Users' Group. He (or she) acts as an advisor during the evaluation and selection of proposals in response to the various AO's.

(5) Related Programs.

It should be recognized at this early stage that the facility is useful not only for solar X-ray imaging but for similar work on cosmic X-ray sources. Many of the present FDT members also have considerable interest in this area, and it is therefore natural that a night-time observing program be envisioned. Furthermore, the facility may have some application in the study of small scale auroral features. Since it is unlikely that two nearly identical instruments of this scale will be constructed this facility may well be unique. Coupling the Solar observing program to the requirements for High Energy Astrophysics should result in increased opportunities for both areas.

Furthermore, follow-on studies in solar hard X-rays will require the extended observing time available only in free-flying spacecraft. One would expect that as the shuttle facility nears completion for an early flight, an AO for such a mission would occur. It is natural and cost-effective that such a system follow almost directly from the shuttle facility design, and that many of the same Investigators would be involved. It may even be possible to use a nearly identical instrument, with support subsystems selected from the repertoire implied by the GSFC Standard Spacecraft concept.

B. Management as a PI-led Consortium

(1) Introduction.

The alternative to the management concept outlined above consists of consortium of scientists led by a Principal Investigator, in the normal manner. In this configuration, the Principal Investigator would be identified with the leader of the Facility Definition Team, and the Co-Investigator list would include at least some of the present team members, and possibly other scientists as well. The evolution of the instrument design through the equivalent of a phase B study will probably continue in the format described in Section V-A, under NASA responsibility through the Spacelab Payloads program at GSFC.

(2) Early Spacelab Flights.

The bulk of this report describes the instrument configuration as proposed for Spacelab 2 (1) and OFT (2) opportunities. We list here the responsibilities of each member of the consortium and the management structure developed to successfully guide this project from an initial planning stage through instrument development, data acquisition, reduction and analysis and future Hard X-Ray Imaging Instrument missions. UCSD, in conjunction with hardware subcontractors, will be responsible for flight instrument development. The basic assumptions which form the basis of project planning are listed. We further describe the expected evolution of the program into a multi-user instrument.

The Spacelab Hard X-Ray Imaging Instrument will involve at least seven institutions working closely with one another and receiving direction and assistance from NASA. The entire project is to be under the direction of the Principal Investigator, who is the spokesman of the Investigator team and bears ultimate responsibility to NASA. Hardware to be delivered under this program will be the responsibility of the Principal Investigator. It is envisioned that separate contracts will be issued from NASA to each of the participating team members' institution for support of scientific direction and data analysis, with a separate contract to UCSD for the Principal Investigator's support and all deliverable hardware costs. The planned interrelationships among these organizations are discussed here and summarized in Figures V-2 and V-3. The detailed responsibilities of individual Co-investigators remain the same as in Section V-A.

Contracts and a Memo of Understanding between the Co-investigators institutions and NASA should be direct and not include UCSD. In the case of UCB, where hardware is being furnished, only the hardware development and support costs would be channeled through UCSD. This relationship is illustrated in Figure V-2. The responsibilities of each team member are listed in Figure V-3.

For the above summarized organizational relationship, the responsible NASA Center will have a single point of contact through the Principal Investigator at UCSD and will also have direct access to any of the organizational elements. It is expected that day-to-day technical coordination will be between NASA and the UCSD experiment manager.

The organization shown in Figure V-4, established at UCSD to assist the Principal Investigator in the management and conduct of the program, includes an Experiment Manager and a full-time Experiment Scientist. The Experiment Manager is responsible for the day-to-day operation of the program and will work closely with the Experiment Scientist to assure that the scientific objectives of the experiment are achieved. He will be responsible for technical, financial and schedule direction of UCSD personnel and of the subcontractors. He will act as the interface with NASA, the integration contractor, and other experiment contractors.

The Experiment Scientist will assure scientific coordination with all coinvestigators, and will provide scientific direction of the design, development, testing and data reduction throughout the life of the program. Assistant to the Program Scientist and Principal Investigator will be graduate students engaged in X-ray and gamma ray astronomy. These students will provide calculations for design parameter changes, and will assist in instrument testing and test data analysis as well as mission design.

Reporting to the UCSD Experiment Manager is a staff of engineers, technicians and programmers to provide design and technical support. In addition, an Administrative Assistant is responsible for cost accounting, purchasing and data management. He approves for payment of all invoices, monitors the material and labor costs, prepares projections and reports financial status to the Program Manager and NASA. All purchase requests are processed by the Administrative Assistant. He determines documentation requirements, insures timely submittal and distributes and files all incoming program documentation. He also maintains the engineering documentation file, maintains configuration control and engineering release.

HARD X-RAY IMAGING INSTRUMENT

OPERATIONAL STRUCTURE FUNDING & DIRECTION

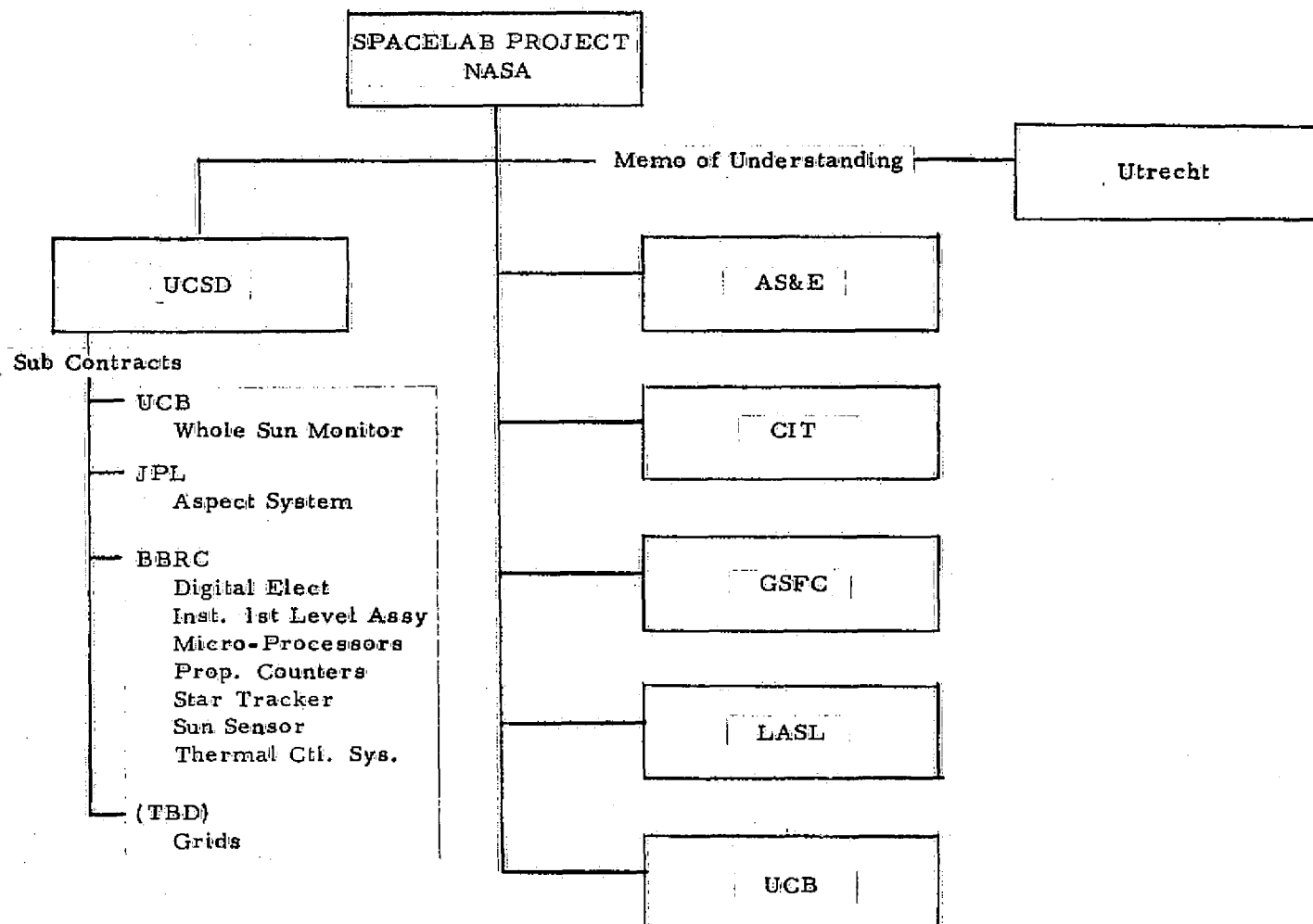
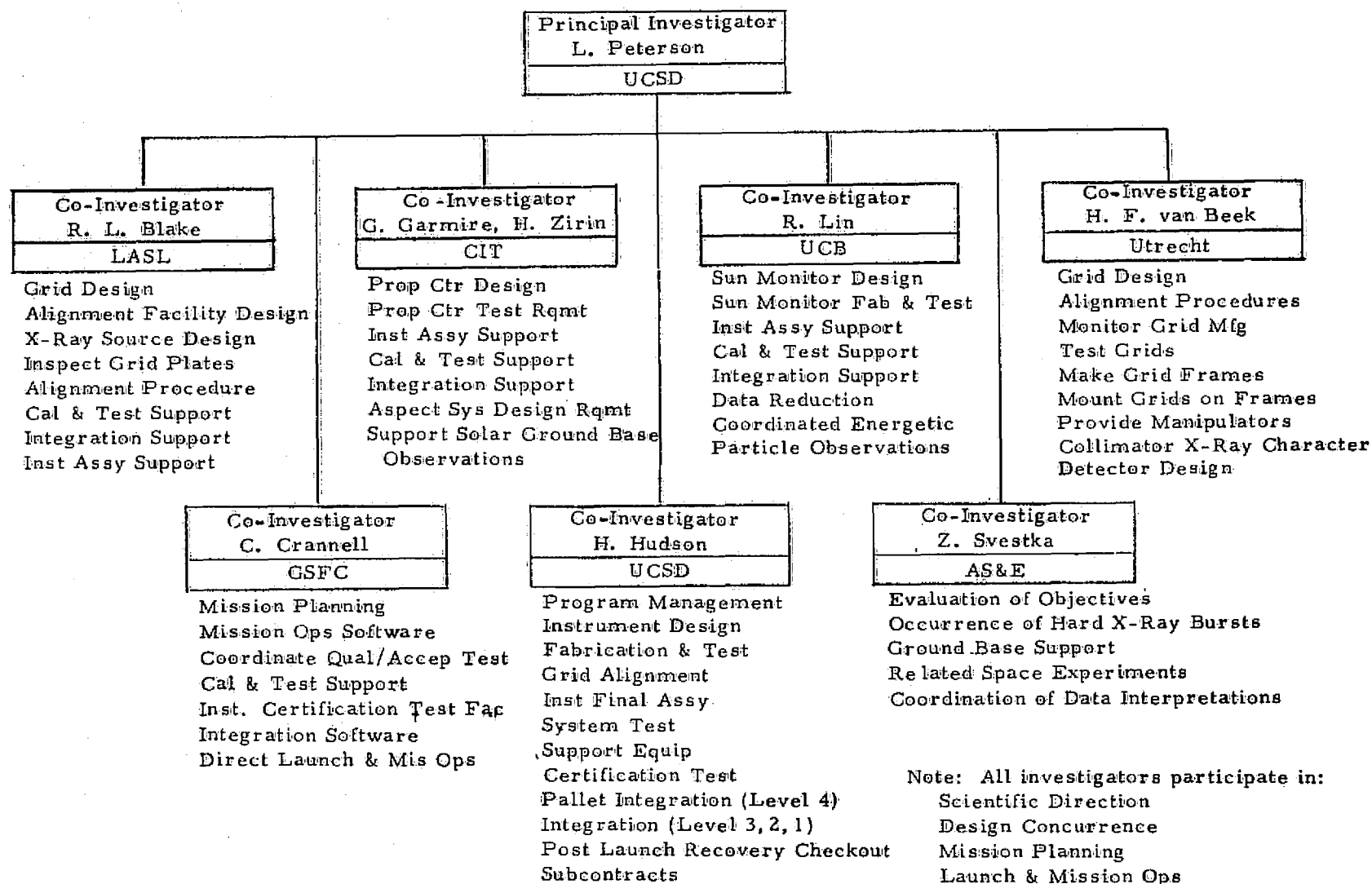


Figure V-2

HARD X-RAY IMAGING INSTRUMENT ORGANIZATION



Note: All investigators participate in:
Scientific Direction
Design Concurrence
Mission Planning
Launch & Mission Ops
Final Report
Data Analysis

Figure V-3

HARD X-RAY IMAGING INSTRUMENT EXPERIMENT MANAGEMENT AT UCSD

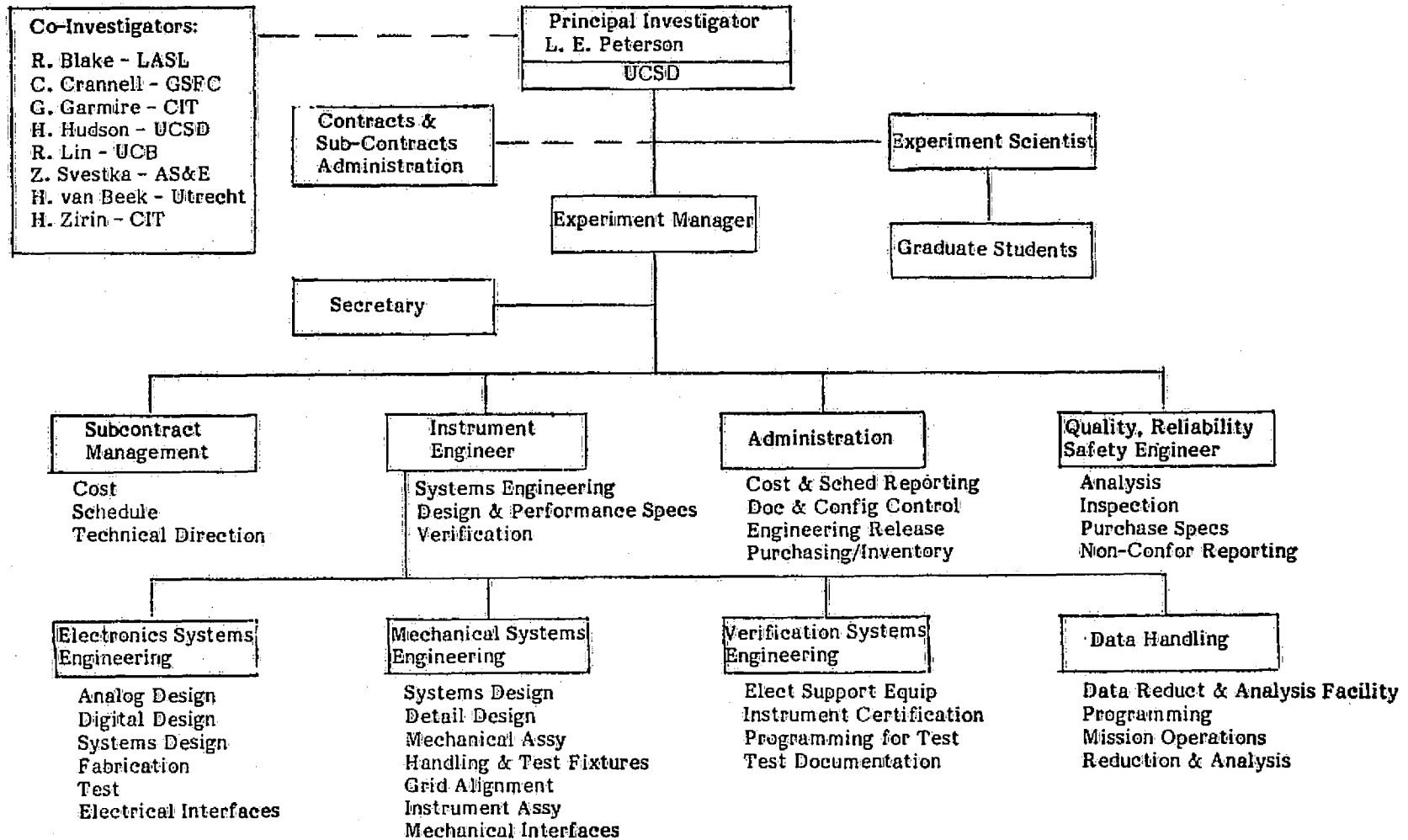


Figure V-4

(3) Assumptions for Spacelab-2 Program.

(a) Schedule

For planning and costing purposes, the following milestones, actions and dates are assumed:

March 1977	Notification of instrument selection.
April 1977	Funding for definition studies.
July 1977	Subcontractor selected prior to commencement of hardware development phase.
October 1979	Deliver flight instrument for pallet integration.
October 1980	Launch 7-Day Mission - One year post mission data reduction and analysis.
January 1981	Final report, preliminary draft.
December 1981	Final report.

(b) Instrument

1. Proto/flight instrument concept (one instrument).
2. Electronics breadboard of new systems.
3. Engineering verification unit at the unique module level for development testing and design verification to include:
 - Structure/Thermal
 - Proportional Counter
 - Digital S/C interface
 - Special purpose designs
4. Spares of critical mechanical and electrical piece parts.
5. Design to include thermal control system.

(c) Manufacturing

1. Maximum use of UCSD manufacturing facilities.
2. End item to be built to development release design.
3. Design baseline established after end item is assembled.
4. Major subcontractors to be selected for instrument sub-systems and instrument first order assembly.

(d) Testing

1. Breadboard testing of proportional counter.
2. Maximum utilization of UCSD (OSO and HEAO) support equipment.

3. Support equipment to simulate the spacecraft interface will be developed to operate instrument.
4. Instrument final assembly grid alignment and calibration to be performed at UCSD.
5. Instrument certification testing to be performed at and utilizing GSFC test facilities.
6. Environmental testing and instrument certification on the assembled flight instrument.
7. Thermal-vacuum and vibration testing performed to expected flight environmental levels.

(e) Programmatic

1. Program management and reporting to utilize OSO and HEAO experience.
2. Instrument development and delivery to NASA by UCSD.
3. All hardware subcontracts to be let by and administered by UCSD.
4. All NASA regulations, controls, specifications and milestone dates available at start.
5. Design baseline established after assembly of flight unit and prior to final certification testing.

(f) Reliability, Quality Assurance and Safety

1. Safety requirements will be met.
2. No numeric reliability goal is assumed, but highest probability of success is consistent with the overall program objectives.
3. A quality assurance based on the MSFC approved plan for HEAO A-4 instrument will be used.
4. The Material Review Board will consist of a responsible UCSD Designer and a PI representative.
5. Government source inspection at UCSD and its subcontractor is not baselined, except for final acceptance of end item.

(g) Configuration Control

1. Present interval UCSD configuration control management system will be used, based on the interface and end item specifications established at PDR and on the design baseline established at CDR.
2. Class 1 change control will be applied to the above baselines.
3. As as-built configuration document and identification list will be delivered with the instrument.

(h) Level IV, III, II, I Integration

1. The UCSD will provide field support, assisted by sub-contractors and Co-investigators, at the Level IV, III, II, I integration sites as required.

(i) Mission Support

1. The GSFC Co-investigator will provide mission support, at the Payload Operations assisted by UCSD and the Co-investigators, as required.

(j) Post Mission Support

1. The UCSD will provide for post-launch recovery, instrument checkout and planning for instrument refurbishment for future missions.

(4) Evolutionary Program.

The grid collimator concept affords a great deal of flexibility: for optimization in specific problem areas, and for improvement through upgrading of the instrument itself. These attributes will result in an evolutionary program of Spacelab flights, together with the use of related instruments in free-flying spacecraft. Table V-1 displays a possible sequence of evolutionary steps.

The optimization of the instrument for specific problem areas involves the grid and detector configurations. Many possible grid configurations appear in Section III of this report; the specific choice described in Section I optimizes the mapping of hard X-ray sources with diameter on the order of 1 arc min, specifically the impulsive phase of solar flares and the Crab Nebula. An additional design requirement, also reflected in the Spacelab 2 design (1), involved the mapping of sources of around 20 arc min diameter: solar coronal sources and clusters of galaxies. A deep survey for hard point sources, on the other hand, would require a totally different configuration, as would the precise location of transient sources in a very wide field of view. Changes of this type fit naturally into the grid collimator instrumentation: new configurations can be obtained simply by re-designing the grids.

Detection systems may also evolve. The addition of a layer argon-filled proportional counters in front of the xenon counters would give lower background soft X-ray performance. Planar high-purity germanium detectors would give excellent energy resolution for hard X-rays, as a replacement for the xenon counters. The arrangement of image elements in subcollimators of finite size makes this quite practicable.

Finally, the establishment of free-flying X-ray observatories will permit a great amplification of our capability for X-ray imaging via the "pinhole telescope" concept (3). Such systems give extremely high

TABLE V-I
EVOLUTIONARY PROGRAM

<u>Flight</u>	<u>Observational Goals</u>		<u>Angular Resolution arc sec</u>	<u>Energy Range keV</u>	<u>A eff cm²</u>	<u>Field of View</u>		<u>Pointing System</u>	<u>Unique Hardware</u>
	<u>Solar</u>	<u>Cosmic</u>				<u>Periodic</u> arc min	<u>Total</u> arc min		
SMM	Burst Location	None	8	3-30	2.5	---	3.73	SMM	Separate Development
OFT-6	Burst sizes/shapes; Coronal Sources	Crab Nebula	4	2-40	17	0.73	49	Orbiter	Complete System
Spacelab 2	Burst location; Soft X-ray Structure	Crab Nebula; Cluster Sources	4	2-40	26	2.0	40	IPS/other	Complete System
V-17 Spacelab a	Nuclear lines; γ-ray continuum	Nucleosynthesis; Fe-line mapping	4	2-150	26	2.0	40	IPS/other	Grids, Ge Detectors
Spacelab b	Flare granular structure	Source identifi- cation	1	2-150	22.8	---	30	IPS/other	Grids
Free Flyer	White-Light Flare	Source Vari- ability	1	2-150	22.8	2.0	40	Support Module	
Pinhole	Flare Limiting structure	Source identifi- cation	0.1	2-10 ⁴	2x10 ⁴	---	2.0	Space- craft attitude	Remote Satellite

angular resolution, defined by a single remote mask on a separate sub-satellite. All of the rest of the systems of the hard X-ray imaging instrument, previously used as a Spacelab telescope or as a free-flying observatory, then become essentially a pre-collimator for the pinhole telescope.

(5) Management of Evolved Instrumentation.

The consortium responsible for creation of the initial instrumentation, and its observing program, would then relinquish its position. Subsequent flights with their corresponding modifications to the instrumentation would be administered through the Announcement of Opportunity system. The experimenter group built around the Facility Definition Team will then have to compete for observing time and equipment in the normal manner, or else dissolve into re-arranged groupings oriented toward specific observational problems.

References

- (1) "A Hard X-Ray Imaging Instrument For Spacelab 2," UCSD proposal to NASA, 1976.
- (2) "A Hard X-Ray Imaging Instrument For OFT," UCSD proposal to NASA, 1976.
- (3) "Large-Scale Telescopes For X-Ray And Gamma-Ray Astronomy," by H.S. Hudson and R.P. Lin, submitted to Space Science Instrumentation, 1978.